SCOTTISH LIME CENTRE TRUST

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REPORT ON MORTAR ANALYSIS BY X-RAY DIFFRACTION (XRD)

AP 3480
Inverkeithing Town House
Inverkeithing Stone and Slate Audit

Sample 4

Harling from the rear elevation

SITE	Inverkeithing Town Hall, Inverkeithing Stone and Slate Audit
CLIENT	Fife Historic Buildings Trust
DATE SAMPLE RECEIVED	11/12/2019
ANALYSIS DATES	11/12/2019 – 28/03/2020
ANALYSIS, INTERPRETATION & REPORT BY	Dr Katie Strang and Roz Artis
CLIENT REQUIREMENTS	Mortar Analysis by X-ray diffraction
STRUCTURE DATE	1770
STRUCTURE TYPE	Town Townhouse
MORTAR DATING	Original?
LOCATION/ FUNCTION IN BUILDING	Mortar taken at 1.2m height at rear elevation
CONDITION OF SAMPLE RECEIVED	The sample received consisted of a bag containing intact piece of mortar plus fines Size of largest piece = 137.85mm x 87.12mm x 65.14mm Total mass of sample received = 129.33 grams

GENERAL COMMENTS

On the basis of the results from the XRD analysis, it is indicated that the mortar analysed had been mixed from a ‘as dug’ marine sand, and a non-hydraulic to feebly hydraulic lime binder. The appearance of the lime inclusions suggests it was most likely prepared as a ‘hot mixed’ lime mortar by slaking quicklime and sand together in one operation. The lime inclusions may also indicate it was prepared as a putty, that was not well screened prior to use, or as a dry hydrate. Further analysis by petrography can be undertaken to confirm this.

The mix ratio of the sample is approximately 1 part non-hydraulic to feebly hydraulic quicklime or dry hydrate to 0.62 parts aggregate (by volume).

The sample was to be submitted to analysis by X-ray Powder Diffraction to establish the crystalline components present, to ascertain the type of binder used. The sample was sent to the laboratory at The Concrete Technology Unit, University of Dundee, for XRD analysis and all interpretation carried out by Dr Katie Strang of SLCT.

ANALYTICAL PROCEDURES

The sample was initially photographed on receipt in the laboratory, logged with its mass and size recorded prior to the sample being submitted to an examination with the aid of a stereo-binocular microscope at a magnification up to x20. During the examination the sample was exposed to a series of *ad hoc* droplet tests employing a range of reagents and indicator solutions to aid the identification of the components present and to assess the condition of the mortar.

Following the examination, a representative sub-sample was obtained to permit confirmation of the type of binder used in the mortar to be prepared, with this analysed by X-ray Diffraction (XRD). This was achieved by disaggregating the sample by gently grinding it in an agate mortar and pestle to separate the binder from the aggregates, with the binder recovered by sieving the materials over a 63µm sieve.

The prepared powdered sample was backpacked into a proprietary sample holder in preparation for presentation in the diffractometer, with the sample analysed in a Philips X-ray Diffractometer fitted with a single crystal monochromator, set to run over the range 3° to 60° 2θ in steps of 0.1° 2θ at a rate of 1° 2θ/minute using CuKα radiation. The digital output from the diffractometer was analysed by a computer program, which matched the peak positions against the JCPDS International Standard Mineral Data-base sub files using a search window of 0.1°. Application of 10% Hydrochloric acid to the sample resulted in dissolution of the binder enabling relative proportions of lime (and gypsum) to aggregate to be determined; where appropriate, proportions of insoluble binder were determined and factored into this calculation. Subsequent aggregate characterisation was undertaken by means of dry sieve analysis and microscopic analysis.

The analysis results and interpretations made from it provide information on the composition and characteristics of the mortar sample(s) received by the SLCT laboratory. **Provided the sample was representative of the mortar generally**, the analysis will give a reasonable indication of the original materials and provide a **basis for specification** of repair mortars. If more detailed information is required (for example, for purposes of historic research) more sophisticated analytical procedures can be undertaken.

MORTAR EXAMINATION AND ANALYSIS

Plate 1. Image showing the condition of the sample, as received. Tray diameter c160mm.

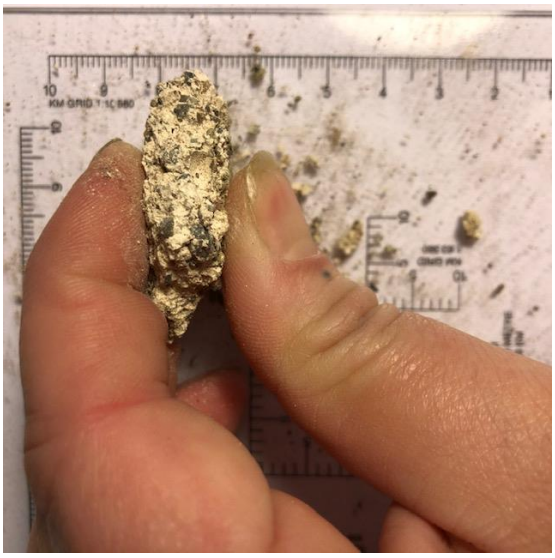


Plate 2. Image showing a fresh face of the mortar, where a large irregular lime inclusion can be seen in the centre. Scale is in mm.

PROCEDURE	OBSERVATIONS
PRELIMINARY VISUAL ANALYSIS OF SAMPLE	The harling was found to be friable and moderately weak and it could be broken under light to moderate finger pressure, and once broken it could be powdered further with ease. The phenolphthalein indicator test confirmed that the mortar was fully carbonated whilst a water droplet test confirmed that the mortar was porous as the droplets were rapidly absorbed and the water diffused throughout the mortar.
EXAMINATION OF PREPARED SAMPLE BY BINOCULAR MICROSCOPE (X40 MAGNIFICATION)	Lime inclusions were observed, and these were sub-round to sub-angular in shape and up to 3.1mm in size. The inclusions had the appearance of a quicklime in hand specimen, and some experienced later reprecipitation of calcite around the margins. Aggregates are dominated by coarse grained well weathered lithic fragments and quartz, they are sub-rounded to sub-angular and sub-spherical in shape and up to 4.8mm in size, and the occasional shell fragment. The intact pieces of mortar, although heavily voided appeared to have been reasonably well compacted, when placed. The mortar contained an abundance of air voids, some of which contained linings of calcite as secondary products, soiling and organic matter, all indicating that water percolation through the mortar had occurred, resulting in leaching, and the re-precipitation, of binder components and the deposition of transported debris.

RESULTS OF XRD ANALYSIS

On the basis of the results from the XRD analysis, it is indicated that the mortar analysed had been mixed from a ‘as dug’ marine sand, and a non-hydraulic to feebly hydraulic lime binder. The appearance of the lime inclusions suggests it was most likely prepared as a ‘hot mixed’ lime mortar by slaking quicklime and sand together in one operation. The lime inclusions may also indicate it was prepared as a putty, that was not well screened prior to use, or as a dry hydrate. Further analysis by petrography can be undertaken to confirm this.

QUANTIFICATION BY RIETVELD REFINEMENT

To assist in clarifying this further the results from the XRD analysis were processed by Rietveld refinement in the Maud Computer program, the results of which are presented below:

Component	**% by mass**
Calcite	85.6
quartz	6.4
hematite	0.4
albite	0.6
gypsum	6.7
dickite	0.2
Total	**100.0**

The results of the analyses are shown in the following figure, in the form of a labelled X-ray diffractogram:

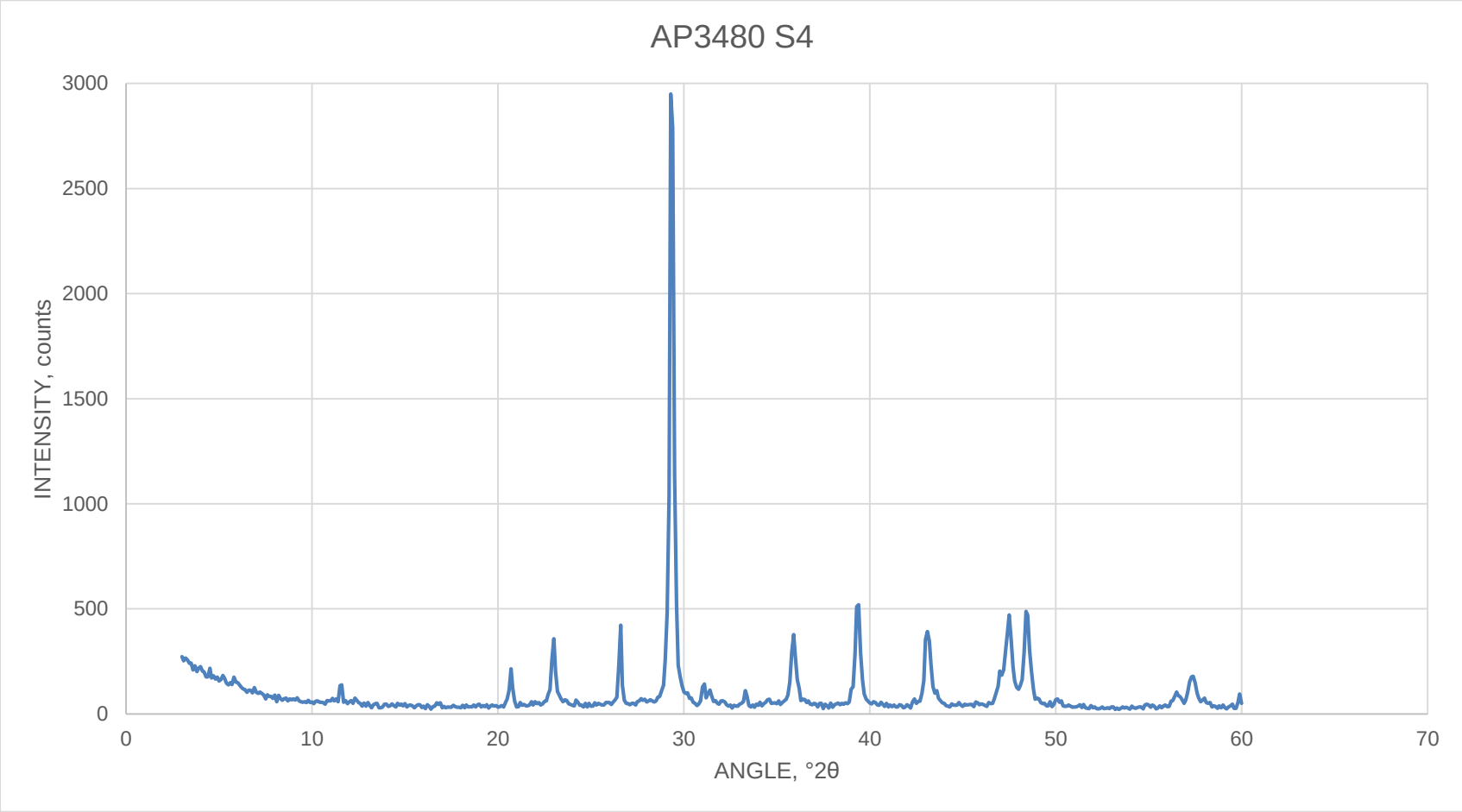


Figure No. 1: Harling from Inverkeithing Town Hall, Rear elevation

COMMENTS

The abbreviations used on the chart, to identify peak positions, are as follows:

cc = Calcite ($CaCO_3$) calcium carbonate, carbonated binder from lime type binders,
qz = Quartz (SiO_2) dominant component of the aggregate in the mortar,
fs = Feldspar minerals, including albite, aggregate minerals in the sands,
he = Hematite, iron oxide, commonly used as a pigment, or present as an aggregate component
gy = Gypsum, calcium sulphate hydrate, sulphate reaction product
di = Dickite, clay mineral, aggregate component.

On the basis of the results from the XRD analysis, it is indicated that the mortar analysed had been mixed from a ‘as dug’ marine sand, and a non-hydraulic to feebly hydraulic lime binder, most likely prepared as a ‘hot mixed’ lime mortar by slaking quicklime and sand together in one operation, or as a dry hydrate. Further analysis by petrography can be undertaken to confirm this.

CONSTITUENTS OF ANALYSIS SAMPLE

MATERIAL	WEIGHT (g)	COMMENTS
A: DRY WEIGHT OF ANALYSIS SAMPLE	39.74	Mass of sample analysed (before acid digestion).
B: DRY WEIGHT OF ALL INSOLUBLES	21.97	Insoluble residue recovered after acid digestion (before sieving).
C: DRY WEIGHT OF INSOLUBLE BINDER	0.00	Determined from microscopic examination of filter residue (presence of insoluble hydraulic components can be confirmed by XRD analysis).
D: (B-C) DRY WEIGHT OF AGGREGATE	21.97	Corrected for retention of hydraulic components or other non-soluble reaction products.
E: (A-D) DRY WEIGHT OF LIME	17.77	Including insoluble binder where present.
MOISTURE CONTENT (%)	3.64	Based on mass of sample before and after drying.
OTHER	Gypsum present (XRD)	Gypsum and other non-binder related contaminants or reaction products.

AGGREGATE GRADING & CHARACTERISATION

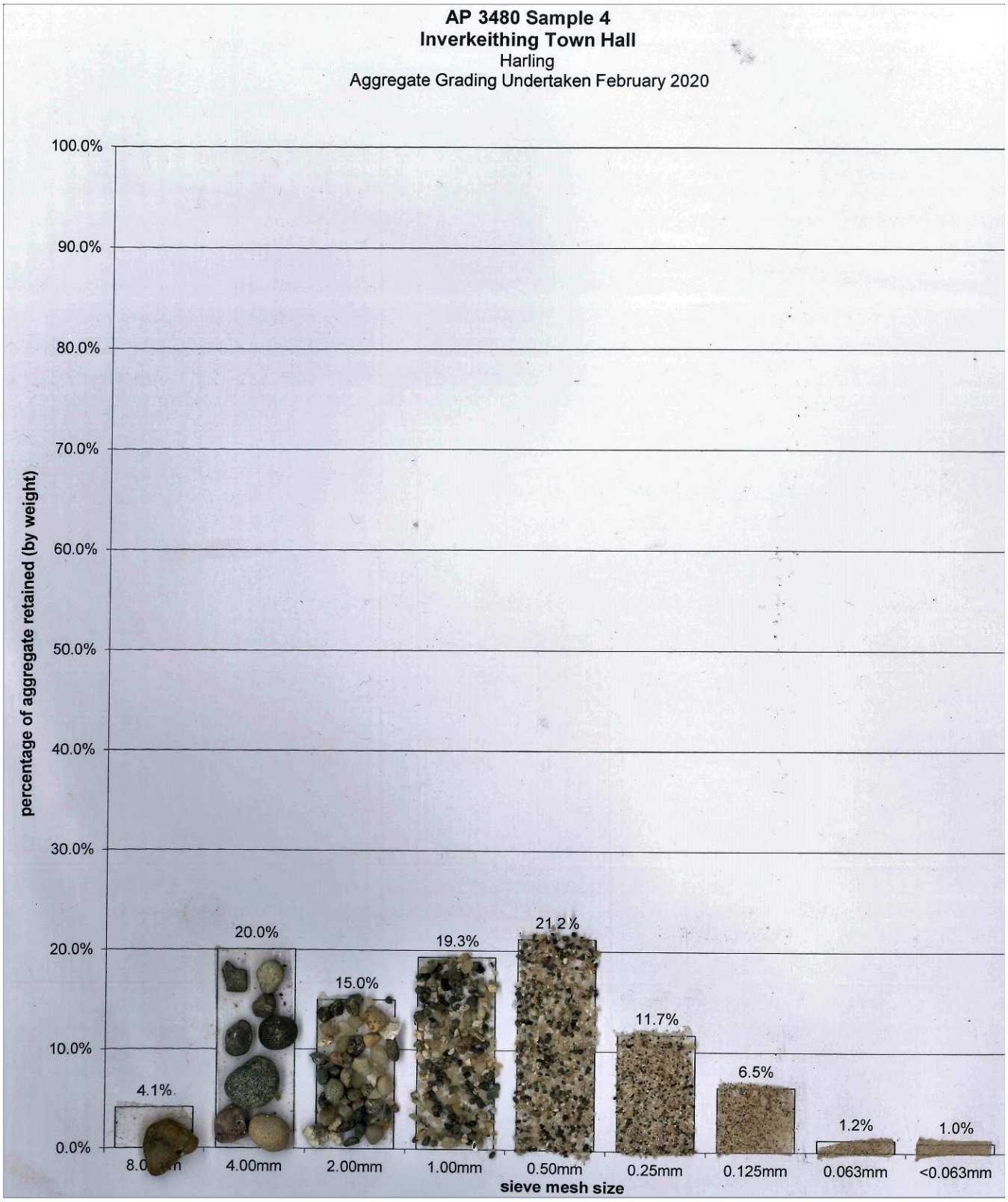
SIEVE PERFORATION SIZE*	AGGREGATE RETAINED (g)	UNDISSOLVED BINDER (%)	CORRECTED AGGREGATE WEIGHT (g)	% OF AGGREGATE	COMMENTS
8mm	0.84	0	0.84	4.1	Sub-rounded to sub-angular, sub-spherical and well weathered lithic fragments.
4mm	4.00	0	4.00	19.7	As above plus sub-angular cloudy textured buff/creamy/grey quartz grains
2mm	3.07	0	3.07	15.1	As above
1mm	3.95	0	3.95	19.4	As above
500µm	4.33	0	4.33	21.3	Predominately sub-angular cloudy textured buff/brown/grey quartz grains
250µm	2.39	0	2.39	11.7	As above
125µm	1.32	0	1.32	6.5	As above
63µm	0.25	0	0.25	1.2	As above with indiscernible silt and clay.
< 63µm including filter residue	0.20	0	0.20	1.0	As above with indiscernible silt and clay.

***Sieve perforation sizes correspond to those stated in BS EN 1015.1:1999**

The aggregate isolated from this sample is poorly to moderately well graded and aggregate is retained from sieve size 8mm down with the highest percentage of grains being retained in sieve mesh size 0.500mm with 21.3%. Well weathered lithic fragments and sub angular quartz make up the courser fractions. Smaller fractions are composed predominately of lithic fragments and angular to sub-angular quartz grains and the buff/orange/cream tinted grains give the sand its overall pale brown colour. See aggregate profile below.

Because sand and gravel aggregates are ultimately derived from the weathering of solid rock, most aggregates contain course grained rock fragments and finer mineral grains. Physical weathering breaks down the rock fragments within the aggregate into the constituent minerals, resulting in smaller and rounder particles; chemical weathering breaks down unstable minerals, such as feldspars resulting in the formation of clay, which may be washed away. Both weathering processes eventually result in the formation of quartz-rich sand.

Aggregate Profile of the Aggregate Separated from the Mortar Sample



AGGREGATE MATCHING

The closest commercially available matching aggregate, from the SLCT Sands and Aggregates Database taking into account location, grading, grain size, colour and texture is Concrete Sand from Melville Gates Quarry (see aggregate profile below). This sand has been retained from sieve mesh size 4mm down, with the highest percentage of grains being retained from sieve mesh size 0.250mm with 25.2%. It is predominantly medium grained with a uni-modal grain size distribution, lithic fragments give a slightly darker colour and a more buff colour is due to the silts and clays at finer fractions with quartz grains present throughout.

An alternative aggregate match is Concrete Sand from Lomond Quarry (see aggregate profile below). This sand has been retained from sieve mesh size 4mm down, with the highest percentage of grains being retained from sieve mesh size 0.125mm with 26.7%. It is well graded with a uni-modal grain size distribution, lithic fragments give a slightly darker colour and a more buff colour is due to the silts and clays at finer fractions with quartz grains present throughout.

Contact details for these quarries are listed below, both are from Fife Silica Sands.

Angle Park Sand & Gravel Co Ltd,
Melville Gates Quarry,
Melville Gates,
Ladybank,
Cupar
Fife
KY15 7RF

Tel.: 01337 830303

Skene Group,
Lomond Quarry,
Balsillie Farm,
Falkland Hills Road,
Leslie,
Fife
KY6 3HD

Tel.: 01592 741 590

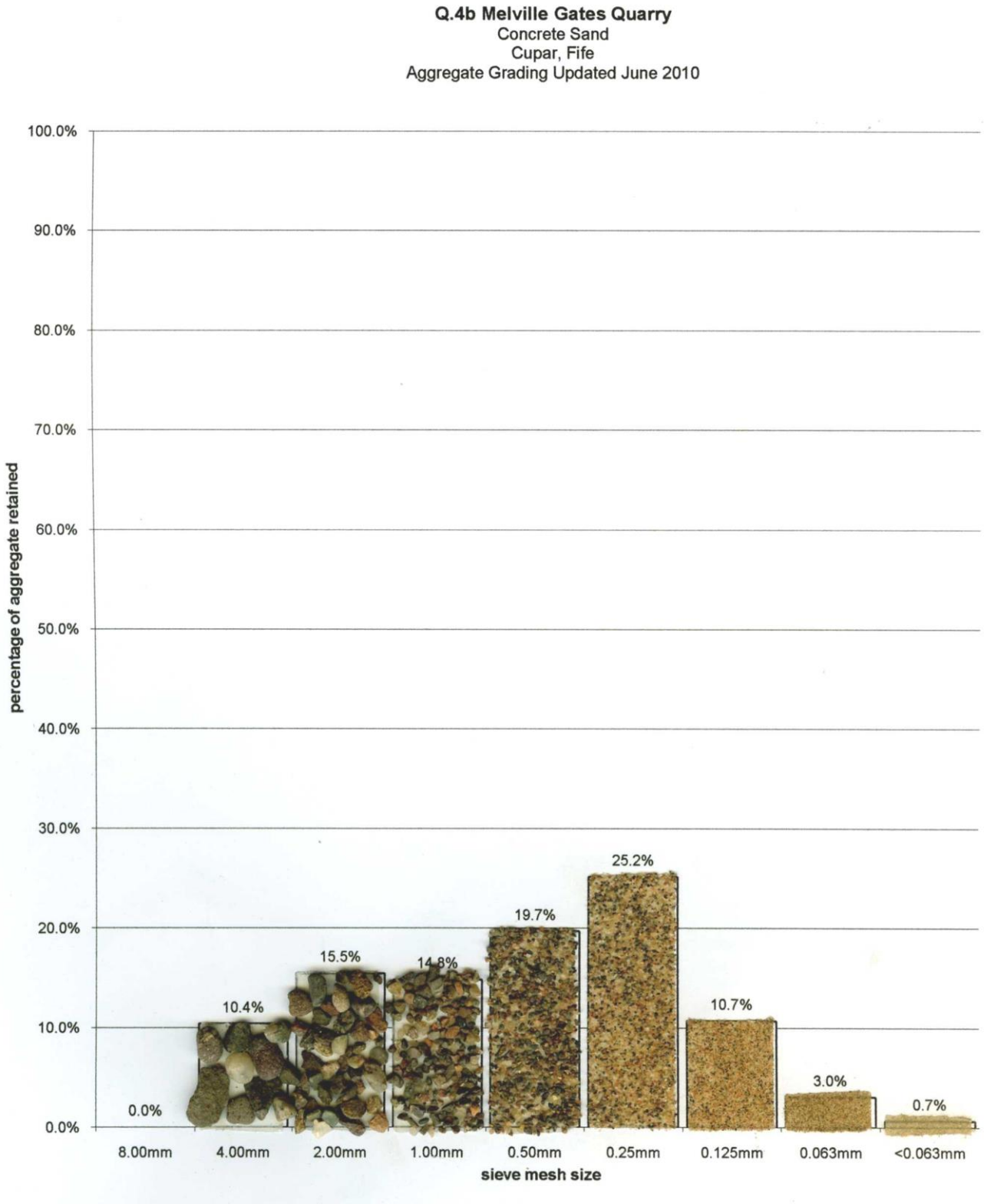
However, the named source(s) is/are not the only potentially suitable source(s) available, but is/are the closest, with respect to visual characteristics and physical properties, on the basis of the work carried out to date, on the sample submitted to examination.

The currently available aggregate samples held in the Scottish Lime Centre Trust's Aggregates Database are provided by the individual quarries/operators and therefore we have to assume that they are representative of the aggregate being produced at the time of receipt of the sample. As with all quarries the actual properties of the aggregate available will be dependent on the area being worked at any given time and it is, therefore, always prudent to obtain samples of the current production for comparison with the aggregate to be matched, prior to ordering supplies for a particular project/application.

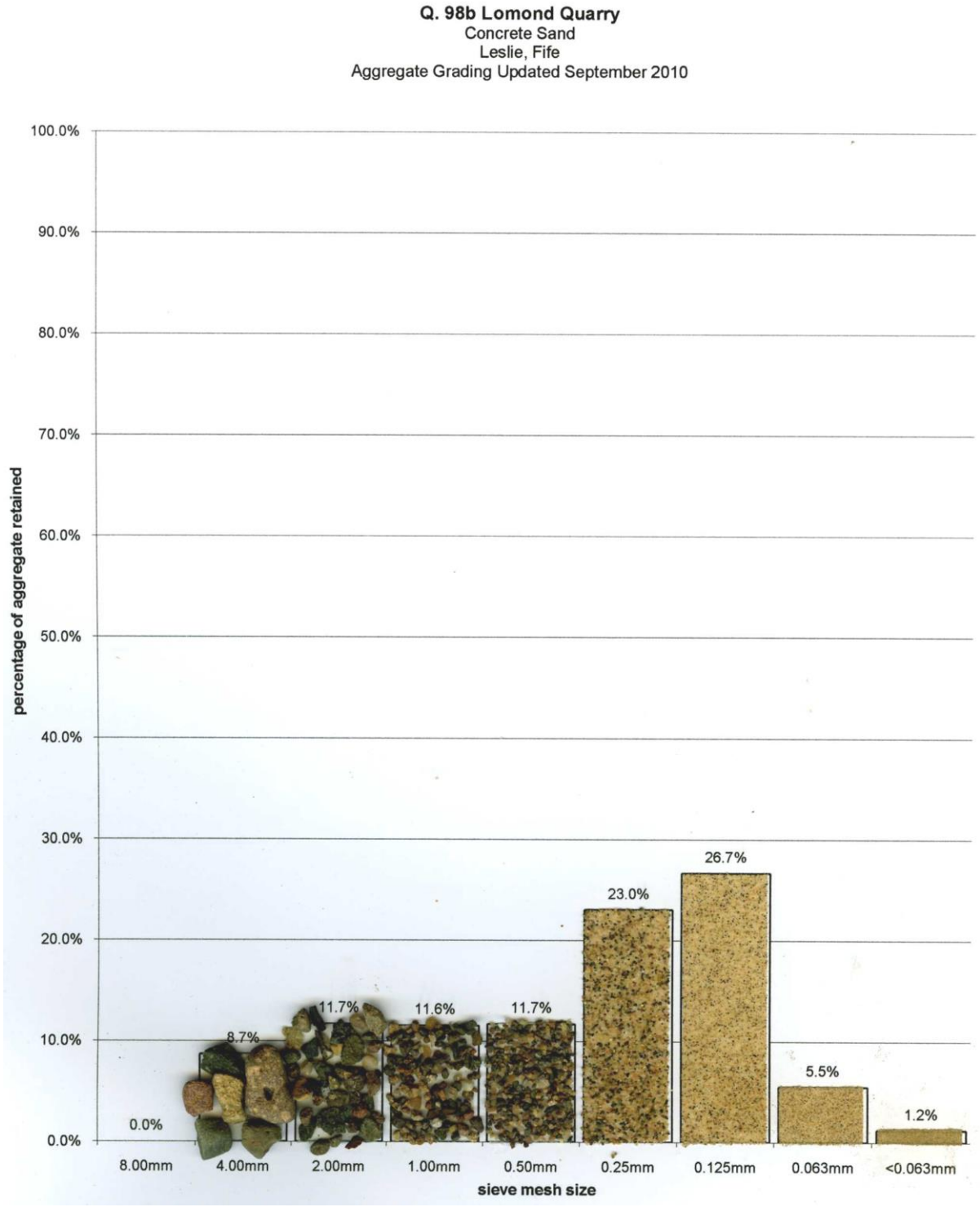
Quarries can change hands, open or close down with a relatively high frequency and therefore the source(s) identified above may become unavailable with no notice. If you are unable to obtain one of the above aggregates within 6 months of us completing this report then we will identify a new source free of charge (after this time period a charge will be incurred).

***If ordered please say that the aggregate was identified by the Scottish Lime Centre Trust.**

Aggregate Profile of the closest Matching Currently Available Aggregate: Concrete Sand, Melville Gates Quarry



Aggregate Profile of an Alternate Matching Currently Available Aggregate: Concrete Sand, Lomond Quarry



PROPORTIONS OF ANALYSIS SAMPLE

The sample proportions give the relative weights of aggregate and carbonated or set lime, unless otherwise stated.

LIME	:	AGGREGATE
1	:	1.2

PROBABLE ORIGINAL MIX

The original mix gives the relative weights of the mortar constituents as mixed on site and before carbonation. From the nature of the binding matrix of the mortar sample and from information gained from the analysis, it is probable that the mortar was made up from a non-hydraulic to feebly hydraulic quicklime, putty or dry hydrate.

1 PART NON-HYDRAULIC TO FEEBLY HYDRAULIC QUICKLIME/ PUTTY/ DRY HYDRATE	**:**	**1.6 PARTS AGGREGATE (BY WEIGHT)**

Please note that the proportions given above relate to the sample supplied, this is not a specification. See associated consultancy report for specifications for replacement mortars.

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REPORT ON MORTAR ANALYSIS BY STANDARD MORTAR ANALYSIS AND X-RAY DIFFRACTION (XRD)

AP 3480
Cadora Café,
Inverkeithing Stone and Slate Audit,
Inverkeithing

Sample 6

Harling mortar

SITE	Cadora Café, Inverkeithing Stone and Slate Audit,
CLIENT	Fife Historic Buildings Trust
DATE SAMPLE RECEIVED	11/12/2019
ANALYSIS DATES	11/12/2019 – 20/01/2020
ANALYSIS, INTERPRETATION & REPORT BY	Dr Katie Strang and Roz Artis
CLIENT REQUIREMENTS	Mortar Analysis by acid digestion and X-ray diffraction
STRUCTURE DATE	Mid 19th century
STRUCTURE TYPE	Café
MORTAR DATING	Late 20th century
LOCATION/ FUNCTION IN BUILDING	Harling from top of steps
CONDITION OF SAMPLE RECEIVED	The sample received consisted of a bag containing an intact piece of mortar and fines. Size of largest piece = 114.63mm x 89.31mm x 22.17mm Total mass of sample received = 221.85 grams

GENERAL COMMENTS

On the basis of the results from the XRD analysis, it is indicated that the mortar analysed had been mixed from a well graded sand and a non-hydraulic lime binder, most likely prepared as a 'dry hydrate'. The XRD shows a particularly high gypsum content, which is likely present as a reaction product between atmospheric pollution (possibly acid rain or sulphates from combustion deposits) and lime from the mortar. There was some friability and fabric disruption observed in the samples received. The mortar used on the nearby Fordell's Lodging was informed to be (by former SLCT Trustee involved in the project) composed of 1 part Jura kalk hydraulic lime (made to a putty), to 1 part lime putty (non-hydraulic) to 5 parts Gowrie sand. There is a possibility this was also used on Cadora Café, however there were no hydraulic components picked up in the XRD. The aforementioned gypsum content and fabric disruption can be an indication of binder depletion, which can sometimes lead to inconclusive XRD data, however; to confirm this would require further analysis by both XRD and thin section (petrography).

The mix ratio of the sample is approximately 1 part non-hydraulic dry hydrate to 0.43 parts sand/aggregate (by volume).

The sample was to be submitted to analysis by X-ray Powder Diffraction to establish the crystalline components present, to ascertain the type of binder used. The sample was sent to the laboratory at The Concrete Technology Unit, University of Dundee, for XRD analysis and all interpretation carried out by Dr Katie Strang of SLCT.

ANALYTICAL PROCEDURES

The sample was initially photographed on receipt in the laboratory, logged with its mass and size recorded prior to the sample being submitted to an examination with the aid of a stereo-binocular microscope at a magnification up to x20. During the examination the sample was exposed to a series of *ad hoc* droplet tests employing a range of reagents and indicator solutions to aid the identification of the components present and to assess the condition of the mortar.

Following the examination, a representative sub-sample was obtained to permit confirmation of the type of binder used in the mortar to be prepared, with this analysed by X-ray Diffraction (XRD). This was achieved by disaggregating the sample by gently grinding it in an agate mortar and pestle to separate the binder from the aggregates, with the binder recovered by sieving the materials over a 63µm sieve.

The prepared powdered sample was backpacked into a proprietary sample holder in preparation for presentation in the diffractometer, with the sample analysed in a Philips X-ray Diffractometer fitted with a single crystal monochromator, set to run over the range 3° to 60° 2θ in steps of 0.1° 2θ at a rate of 1° 2θ/minute using Cu$K\alpha$ radiation. The digital output from the diffractometer was analysed by a computer program, which matched the peak positions against the JCPDS International Standard Mineral Data-base sub files using a search window of 0.1°. Application of 10% Hydrochloric acid to the sample resulted in dissolution of the binder enabling relative proportions of lime (and gypsum) to aggregate to be determined; where appropriate, proportions of insoluble binder were determined and factored into this calculation. Subsequent aggregate characterisation was undertaken by means of dry sieve analysis and microscopic analysis.

The analysis results and interpretations made from it provide information on the composition and characteristics of the mortar sample(s) received by the SLCT laboratory. **Provided the sample was representative of the mortar generally**, the analysis will give a reasonable indication of the original materials and provide a **basis for specification** of repair mortars. If more detailed information is required (for example, for purposes of historic research) more sophisticated analytical procedures can be undertaken.

MORTAR EXAMINATION AND ANALYSIS

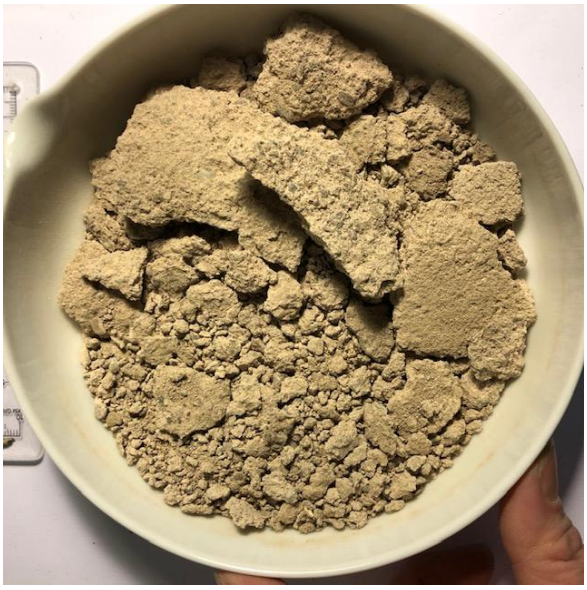


Plate 1. Image showing the condition of the sample, as received. Tray diameter c160mm.

Plate 2. Image showing a fresh face of the mortar. Scale is in mm.

PROCEDURE	OBSERVATIONS
PRELIMINARY VISUAL ANALYSIS OF SAMPLE	The mortar was found to be friable and weak and it could be broken under light finger pressure. Once broken it could be powdered further with ease. The phenolphthalein indicator test confirmed that the mortar was fully carbonated whilst a water droplet test confirmed that the mortar was porous as the droplets were rapidly absorbed and the water diffused throughout the mortar. There was no evidence of burnt fuel/coal fragments or shell aggregate in this sample. The harling appeared to only consist of one coat and varied between 2.15mm to 5.47mm in thickness.
EXAMINATION OF PREPARED SAMPLE BY BINOCULAR MICROSCOPE (X40 MAGNIFICATION)	Lime inclusions were not observed, however, there were small powdery inclusions indicative of leaching or sulphate attack. Aggregates are dominated by quartz with quartzite, granite and indeterminate lithic fragments present, they are angular to elongate in shape and up to 5.2mm in size. The mortar is heavily voided, with the majority of voids containing linings of calcite as a secondary product, soiling and organic matter, all indicating that water percolation through the mortar had occurred, resulting in leaching, and the re-precipitation, of binder components and the deposition of transported debris.

RESULTS OF XRD ANALYSIS

On the basis of the results from the XRD analysis, it is indicated that the mortar analysed had been mixed from a well graded sand and a non-hydraulic lime binder, most likely prepared as a 'dry hydrate'. The XRD shows a particularly high gypsum content, which is likely present as a reaction product between atmospheric pollution (possibly acid rain or sulphates from combustion deposits) and lime from the mortar. There was some friability and fabric disruption observed in the samples .

QUANTIFICATION BY RIETVELD REFINEMENT

To assist in clarifying this further the results from the XRD analysis were processed by Rietveld refinement in the Maud Computer program, the results of which are presented below:

Component	**% by mass**
calcite	67.6
quartz	8.4
hematite	0.8
albite	3.6
gypsum	13.3
dickite	0.3
muscovite	3.1
sodalite	2.9
Total	**100.00**

The results of the analyses are shown in the following figure, in the form of a labelled X-ray diffractogram:

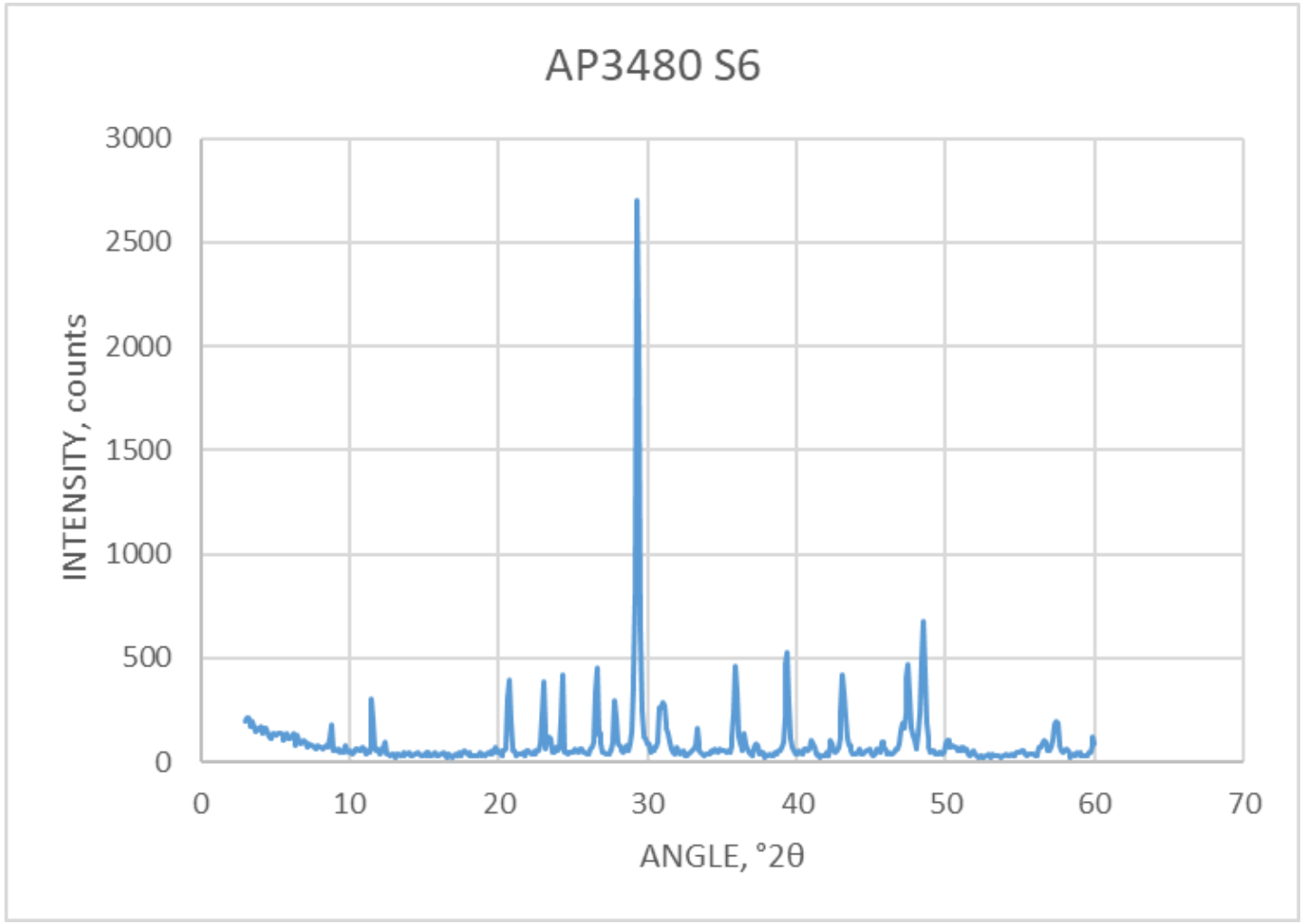


Figure No. 1: Harling from Cadora Café

COMMENTS

The abbreviations used on the chart, to identify peak positions, are as follows:

cc = Calcite ($CaCO_3$) calcium carbonate, carbonated binder from lime type binders,
qz = Quartz (SiO_2) dominant component of the aggregate in the mortar,
fs = Feldspar minerals, including Albite, aggregate minerals in the sands,
he = Haematite, possibly present as an aggregate component, but most likely added as a pigment.
di = Dickite, clay mineral, present in aggregate or as a contaminant
gy = Gypsum, calcium sulphate hydrate, most likely present as an environmental pollution reaction product
mu = Muscovite, aggregate component

On the basis of the results from the XRD analysis, it is indicated that the mortar analysed had been mixed from a well graded sand and a non-hydraulic lime binder, most likely prepared as a ‘dry hydrate’. The XRD shows a particularly high gypsum content, which is likely present as a reaction product between atmospheric pollution (possibly acid rain or sulphates from combustion deposits) and lime from the mortar. There was some friability and fabric disruption observed in the samples received.

CONSTITUENTS OF ANALYSIS SAMPLE

MATERIAL	WEIGHT (g)	COMMENTS
A: DRY WEIGHT OF ANALYSIS SAMPLE	51.81	Mass of sample analysed (before acid digestion).
B: DRY WEIGHT OF ALL INSOLUBLES	24.05	Insoluble residue recovered after acid digestion (before sieving).
C: DRY WEIGHT OF INSOLUBLE BINDER	0.00	Determined from microscopic examination of filter residue (presence of insoluble hydraulic components can be confirmed by XRD analysis).
D: (B-C) DRY WEIGHT OF AGGREGATE	24.05	Corrected for retention of hydraulic components or other non-soluble reaction products.
E: (A-D) DRY WEIGHT OF LIME	27.76	Including insoluble binder where present.
MOISTURE CONTENT (%)	4.51	Based on mass of sample before and after drying.
OTHER	Gypsum present (XRD)	Gypsum and other non-binder related contaminants or reaction products.

AGGREGATE GRADING & CHARACTERISATION

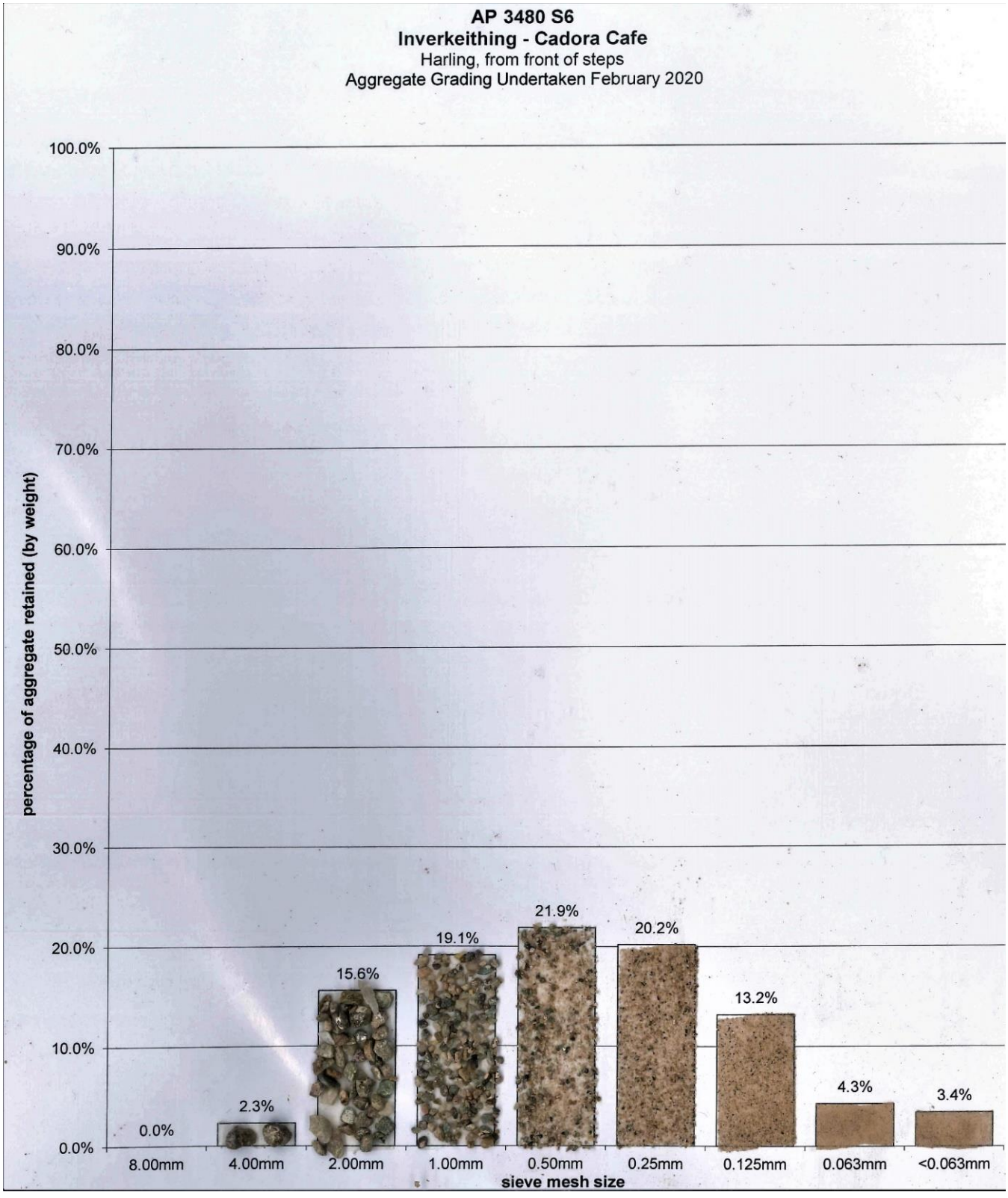
SIEVE PERFORATION SIZE*	AGGREGATE RETAINED (g)	UNDISSOLVED BINDER (%)	CORRECTED AGGREGATE WEIGHT (g)	% OF AGGREGATE	COMMENTS
8mm	0.00	0	0.00	0.0	
4mm	0.47	0	0.47	2.3	Sub-rounded to sub-angular, sub-spherical and well weathered lithic fragments. Plus sub-angular cloudy textured buff/creamy/grey quartz grains
2mm	3.20	0	3.20	16.0	As above
1mm	3.93	0	3.93	19.6	As above
500µm	4.50	0	4.50	22.5	Predominately sub-angular cloudy textured buff/brown/grey quartz grains
250µm	4.15	0	4.15	20.7	As above
125µm	2.71	0	2.71	13.5	As above
63µm	0.86	0	0.86	4.3	As above with indiscernible silt and clay.
< 63µm including filter residue	0.20	0	0.20	1.0	As above with indiscernible silt and clay.

***Sieve perforation sizes correspond to those stated in BS EN 1015.1:1999**

The aggregate isolated from this sample is poorly to moderately well graded and aggregate is retained from sieve size 4mm down with the highest percentage of grains being retained in sieve mesh size 0.500mm with 22.5%. Well weathered lithic fragments and sub angular quartz make up the courser fractions. Smaller fractions are composed predominately of lithic fragments and angular to sub-angular quartz grains and the buff/orange/cream tinted grains give the sand its overall pale brown colour. See aggregate profile below.

Because sand and gravel aggregates are ultimately derived from the weathering of solid rock, most aggregates contain course grained rock fragments and finer mineral grains. Physical weathering breaks down the rock fragments within the aggregate into the constituent minerals, resulting in smaller and rounder particles; chemical weathering breaks down unstable minerals, such as feldspars resulting in the formation of clay, which may be washed away. Both weathering processes eventually result in the formation of quartz-rich sand.

Aggregate Profile of the Aggregate Separated from the Mortar Sample



AGGREGATE MATCHING

The closest commercially available matching aggregate, from the SLCT Sands and Aggregates Database taking into account location, grading, grain size, colour and texture is Concrete Sand from Lomond Quarry (see aggregate profile below). This sand has been retained from sieve mesh size 4mm down, with the highest percentage of grains being retained from sieve mesh size 0.125mm with 26.7%. It is predominantly coarse grained with a uni-modal grain size distribution, lithic fragments give a slightly darker colour and a more buff colour is due to the silts and clays at finer fractions with quartz grains present throughout.

An alternative aggregate match is Concrete Sand from Loanleven Quarry (see aggregate profile below). This sand has been retained from sieve mesh size 4mm down, with the highest percentage of grains being retained from sieve mesh size 0.250mm with 25.5%. It is well graded with a uni-modal grain size distribution, lithic fragments give a slightly darker colour and a more buff colour is due to the silts and clays at finer fractions with quartz grains present throughout. This sand is slightly finer than the analysed sample.

Contact details for these quarries are listed below.

Skene Group,
Lomond Quarry,
Balsillie Farm,
Falkland Hills Road,
Leslie,
Fife
KY6 3HD

Tel.: 01592 741 590

Cemex,
Loanleven Quarry
Almondbank,
Perth
PH1 3NF

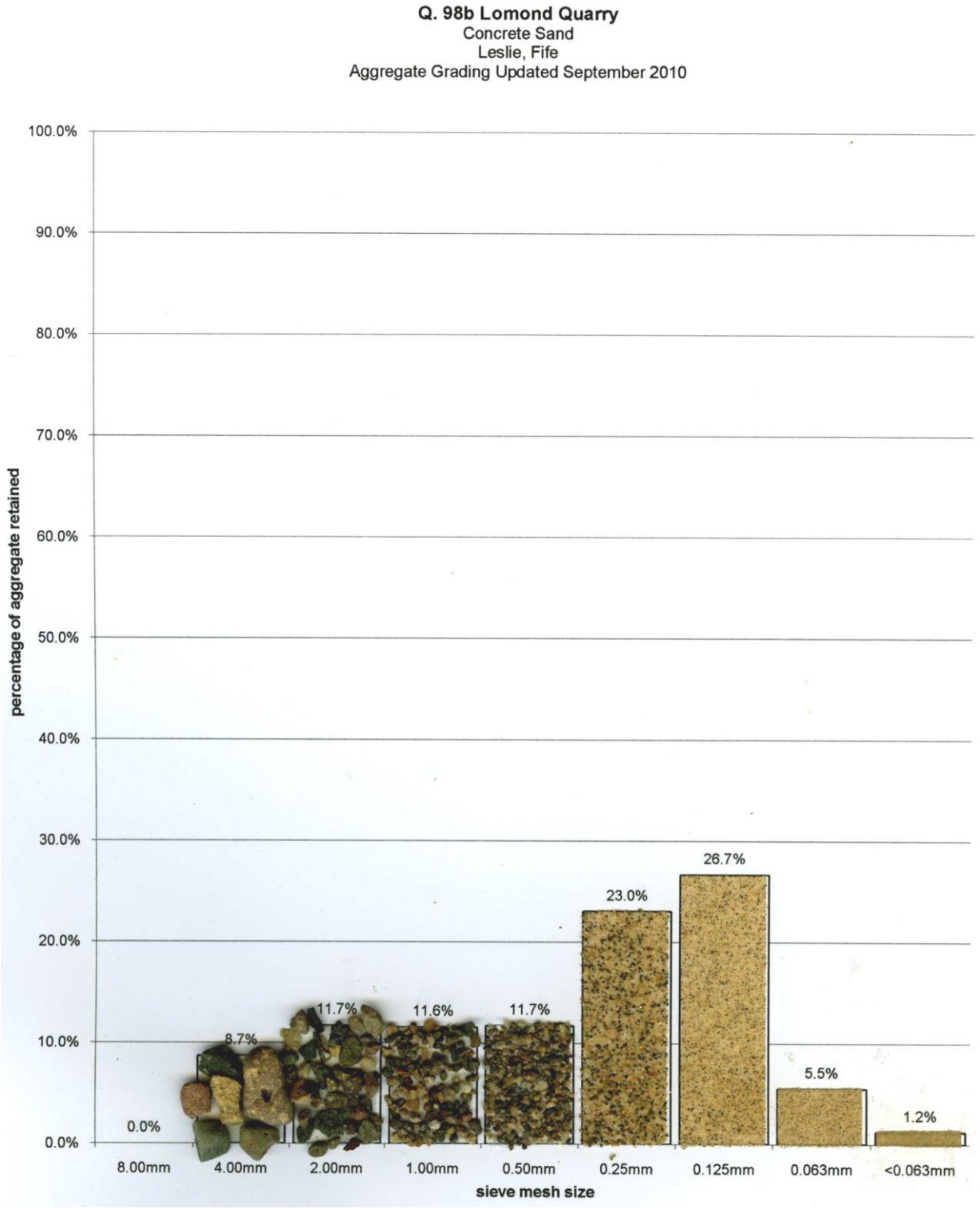
Tel.: 0345 155 1806

However, the named source(s) is/are not the only potentially suitable source(s) available, but is/are the closest, with respect to visual characteristics and physical properties, on the basis of the work carried out to date, on the sample submitted to examination.

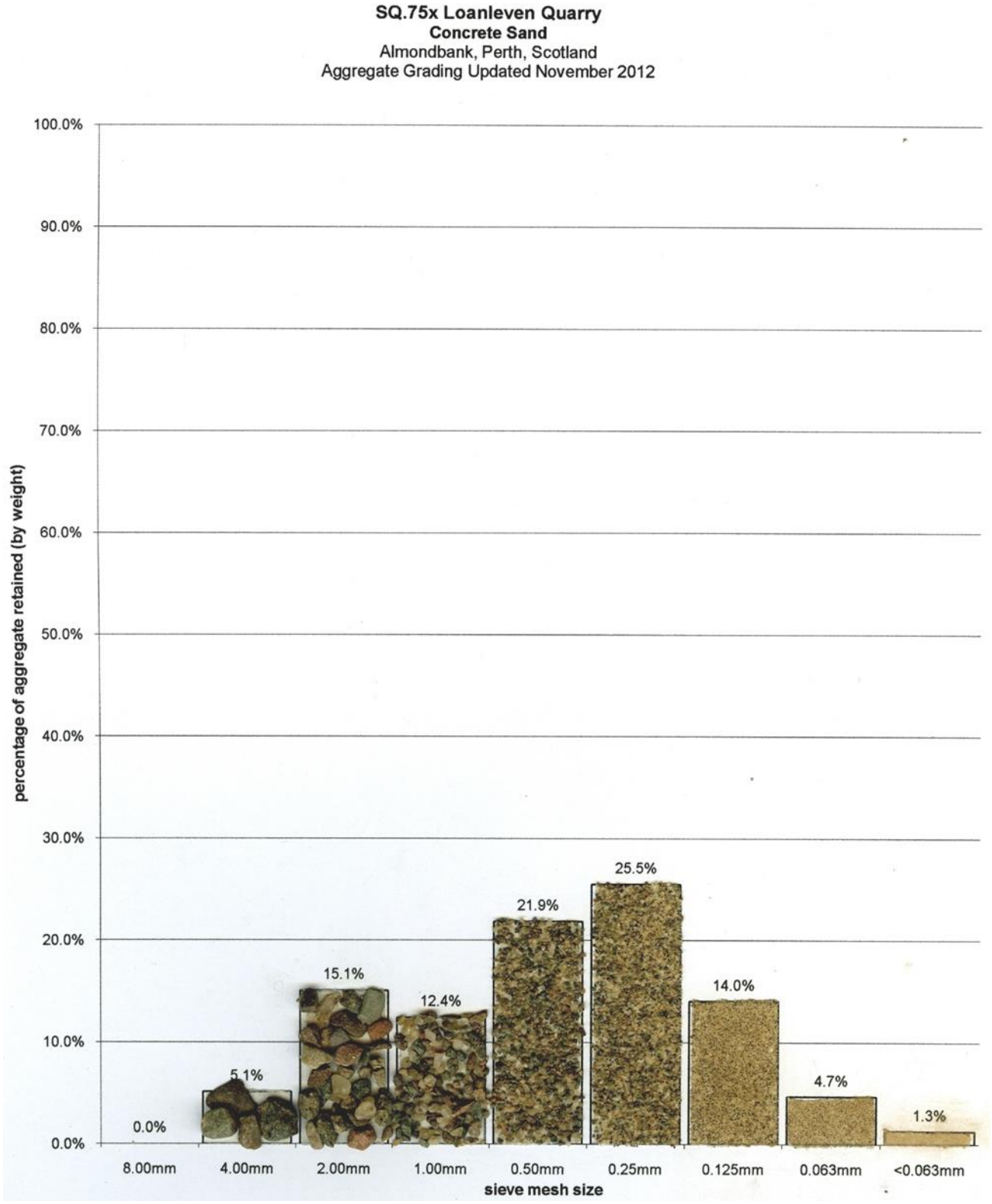
The currently available aggregate samples held in the Scottish Lime Centre Trust's Aggregates Database are provided by the individual quarries/operators and therefore we have to assume that they are representative of the aggregate being produced at the time of receipt of the sample. As with all quarries the actual properties of the aggregate available will be dependent on the area being worked at any given time and it is, therefore, always prudent to obtain samples of the current production for comparison with the aggregate to be matched, prior to ordering supplies for a particular project/application.
Quarries can change hands, open or close down with a relatively high frequency and therefore the source(s) identified above may become unavailable with no notice. If you are unable to obtain one of the above aggregates within 6 months of us completing this report then we will identify a new source free of charge (after this time period a charge will be incurred).

***If ordered please say that the aggregate was identified by the Scottish Lime Centre Trust.**

Aggregate Profile of the closest Matching Currently Available Aggregate: Concrete Sand, Lomond Quarry



Aggregate Profile of an Alternate Matching Currently Available Aggregate: Concrete Sand, Loanleven Quarry



PROPORTIONS OF ANALYSIS SAMPLE

The sample proportions give the relative weights of aggregate and carbonated or set lime, unless otherwise stated.

LIME	:	AGGREGATE
1	:	0.9

PROBABLE ORIGINAL MIX

The original mix gives the relative weights of the mortar constituents as mixed on site and before carbonation. From the nature of the binding matrix of the mortar sample and from information gained from the analysis, it is probable that the mortar was made up from a non-hydraulic dry hydrate.

1 PART NON HYDRAULIC DRY HYDRATE	**:**	**1.1 PARTS AGGREGATE (BY WEIGHT)**

Please note that the proportions given above relate to the sample supplied, this is not a specification. See associated consultancy report for specifications for replacement mortars.

REPORT ON MORTAR
BY X-RAY DIFFRACTION (XRD) AND
PETROGRAPHIC ANALYSIS

AP 3480
Hill Street Boundary Wall,
Inverkeithing Stone and Slate
Audit

Sample 9

Harling

SITE	Hill Street Boundary Wall, Inverkeithing Stone and Slate Audit
CLIENT	Fife Historic Buildings Trust
DATE SAMPLE RECEIVED	19/12/2019
ANALYSIS DATES	19/12/2019 – 09/03/2020
ANALYSIS, INTERPRETATION & REPORT BY	Dr Katie Strang and Roz Artis
CLIENT REQUIREMENTS	Mortar Analysis by petrography and standard analysis
STRUCTURE DATE	Mkd 19th century or earlier
STRUCTURE TYPE	Boundary Wall
MORTAR DATING	Original ? – possibly from previous dwelling.
LOCATION/ FUNCTION IN BUILDING	Harling from the Boundary wall
CONDITION OF SAMPLE RECEIVED	Size of largest piece = 157.1mm x 115.2mm x 99.6mm Total mass of sample received = 175.89 grams

GENERAL COMMENTS

A sample of Harling was sampled from the Boundary Wall on Hill Street, Inverkeithing, to carry out petrographic and standard mortar analysis to ascertain binder composition, binder type, aggregate mineralogy and mix proportions.

The mix ratio of the sample is approximately 1 part non-hydraulic to feebly hydraulic quicklime to 0.42 parts aggregate (by volume).

On the basis of petrographic analysis, it is indicated that this mortar sample was made from a non-hydraulic to feebly hydraulic lime. The lime was most likely made from a hot quicklime, but it appears to have been relatively well slaked; the lime, in the inclusions examined, are well calcined and slaked.

ANALYTICAL PROCEDURES

The sample was initially photographed on receipt in the laboratory, logged with its mass and size recorded prior to the sample being submitted to an examination with the aid of a stereo-binocular microscope at a magnification up to x20. During the examination the sample was exposed to a series of *ad hoc* droplet tests employing a range of reagents and indicator solutions to aid the identification of the components present and to assess the condition of the mortar.

THIN SECTION

Upon receipt in the laboratory the sample was prepared by cutting a slice through one of the larger intact pieces of the mortar, with the specimen aligned such that the slice extended through the full thickness of the sample.

The slice was prepared for thin sectioning by washing the soiling from the sample, which was then dried to a constant weight prior to the vacuum impregnation of the sub-sample with an epoxy resin, to which a fluorescent blue dye had been added. One side of the resin impregnated slice was polished and mounted onto a glass slide (48 x 64mm), with the mounted sample ground and polished to give an approximate thickness of 30 microns.

The thin section was submitted to a microscopic examination, which was undertaken with the aid of a Polarised Light microscope, fitted with a digital camera, to permit recording of photomicrographs, some of which are included in this report, for reference purposes.

The presence of dyed epoxy resin within the sample enables an assessment of the mortar fabric to be made, including an assessment of the visual porosity, void size and distribution along with the evaluation of any crack patterns and physical depositional features apparent in the sample under examination. The sample was examined following standard procedures, and in general accordance with BS EN 12407:2000; Natural Stone Test Methods.

This report presents observations from the microscopic examination.

The analysis results and interpretations made from it provide information on the composition and characteristics of the mortar sample(s) received by the SLCT laboratory. Provided the sample was representative of the mortar generally, the analysis will give a reasonable indication of the original materials and provide a basis for specification of repair mortars. If more detailed information is required (for example, for purposes of historic research) more sophisticated analytical procedures can be undertaken.

INITIAL MORTAR EXAMINATION AND ANALYSIS

Plate 1. Image showing the condition of the sample, as received Dish c160mm diameter.

Plate 2. Image showing the surface of the mortar; note lime inclusions and coal fragments can be observed. Scale is in mm.

PROCEDURE	OBSERVATIONS
PRELIMINARY VISUAL ANALYSIS OF SAMPLE	The harling was found to be moderately hard and it could be broken under light to moderate finger pressure. Once broken it could be powdered further with ease. The phenolphthalein indicator test confirmed that the mortar was fully carbonated whilst a water droplet test confirmed that the mortar was porous as the droplets were rapidly absorbed and the water diffused throughout the mortar. Lime inclusions were observed, and these were sub-round to sub-angular in shape and up to 3.6mm in size. The inclusions had the appearance of a putty lime or quicklime in hand specimen. Aggregates are dominated by quartz, lithic fragments and shell fragments, aggregates tend to be angular to elongate in shape and up to 4.2mm in size. The intact pieces of mortar, although heavily voided appeared to have been reasonably well compacted, when placed. The mortar contained an abundance of air voids, some of which contained linings of calcite as secondary products, soiling and organic matter, all indicating that water percolation through the mortar had occurred, resulting in leaching, and the re-precipitation, of binder components and the deposition of transported debris.

PETROGRAPHIC ANALYSIS - SUMMARY OF MICROSCOPIC OBSERVATIONS

Binder

The binder is fully carbonated and contains relicts of lime inclusions up to 4mm in diameter. Lime inclusions are sub-rounded to irregular in shape and commonly exhibit relic cores, and have the appearance typical of having been placed as a well slaked quicklime in a "hot mixed lime" mortar. The binder is heterogeneous with apparently dense areas adjacent to extremely porous areas. The mortar has undergone extensive depletion and reprecipitation of calcite giving an overall patchy appearance to some regions of the binder, especially towards the outer edges of the sample. Micro-cracks are present and these are typical of plastic shrinkage features. The binder is lime rich. Hydraulic components and un-hydrated clinker were observed in the thin section, but appear to be concentrated within over burnt limestone fragments, suggesting it is a lime-rich, non-hydraulic to feebly hydraulic quicklime. Some of the lime inclusions have the typical hydration/shrinkage micro-cracks common to these particles.

Aggregate

The natural coarse aggregate is dominated by sandstone, whinstone, shale/siltstone and shell fragments; with the fine aggregate again dominated by siltstone/shale, greywacke, and shell fragments, with quartz, limestone and quartzite all present in minor amounts. The sand grains are rounded to sub angular in shape and range in size from 2mm to <0.2mm. Larger particles of rock fragments are locally preserved and are predominantly angular, with some of the larger particles being flaky. Both bivalve and gastropod shell fragments are apparent and range in size from 12mm to <0.2mm. The aggregate is well distributed within the binder and is generally well bonded. The exceptions to this are a number of the shell fragments, which are rimmed by micro-cracks. The aggregate generally appears robust and rarely contain micro-cracks.

Porosity, Voids and cracks

The mortar has a high visual porosity (estimated >15%) and a medium average permeability. The porosity is composed of a high proportion of channel pores within the lime binder and a smaller proportion of large macro-pores. The permeability is variable throughout, with well-connected and highly permeable regions existing between areas of disconnected pores, particularly associated with angular shell fragments. Where there is continuity between pores, the small thin channels between them (also regarded as the channel pores) are very tortuous.

Photomicrographs:

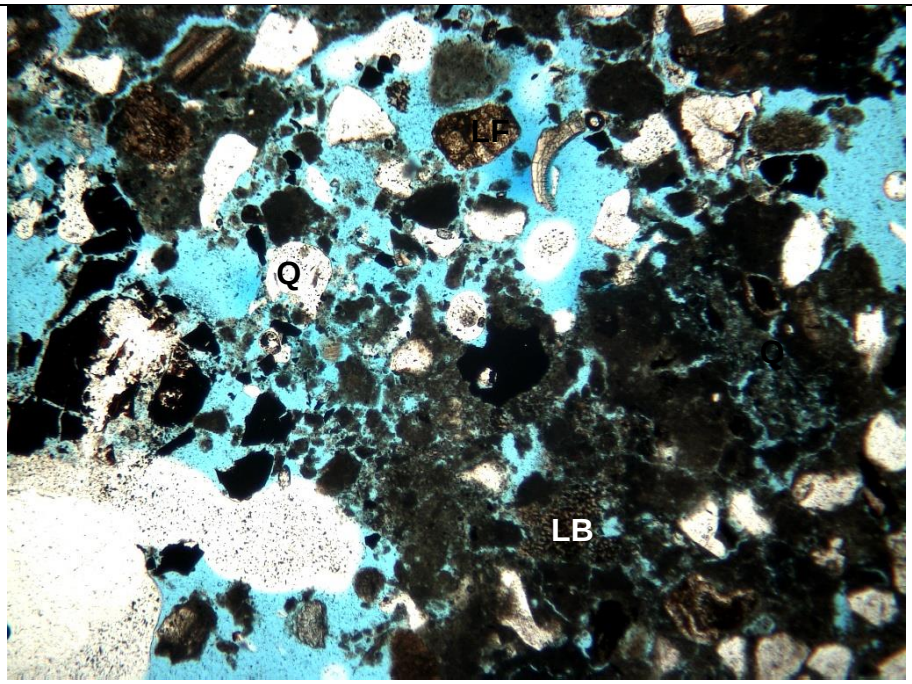


Plate 3. Thin section of the sample under plane polarised light. Pore spaces are highlighted in bright blue, while areas of dark/dull blue indicate the lime binder that has absorbed some of the blue dye. The binder is heterogeneous throughout the sample, with some very porous areas as pictured here. The aggregate shows a range of grain sizes, with several large lithic fragments and shell fragments. LF: lithic fragments, LB: lime binder, Q: quartz.

Field of view: 3.3mm.

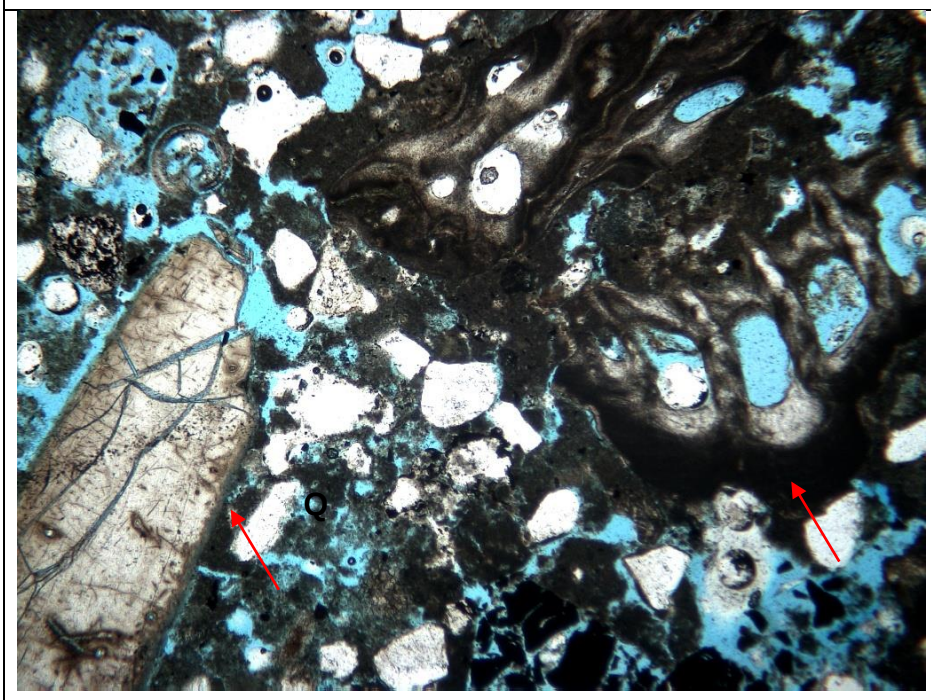


Plate 4. Thin section of the sample under plane polarised light. Pore spaces are highlighted in bright blue, while areas of dark/dull blue indicate the lime binder that has absorbed some of the blue dye). The mortar contains shell fragments, suggesting a beach/local source of aggregate (red arrows).

Field of view: 3.3mm.

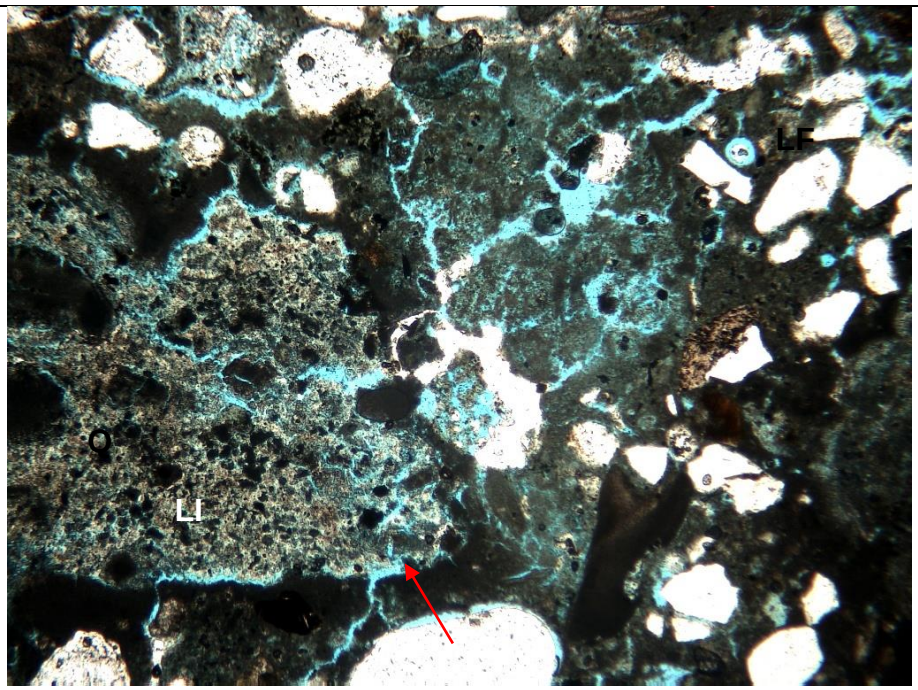


Plate 5. Thin section of the sample under plane polarised light. Pore spaces are highlighted in bright blue, while areas of dark/dull blue indicate the lime binder that has absorbed some of the blue dye. Lime inclusions often exhibit relic cores in the centre and are commonly associated with micro-cracks as seen here (red arrow). LI: lime inclusion.

Field of view: 3.3mm.

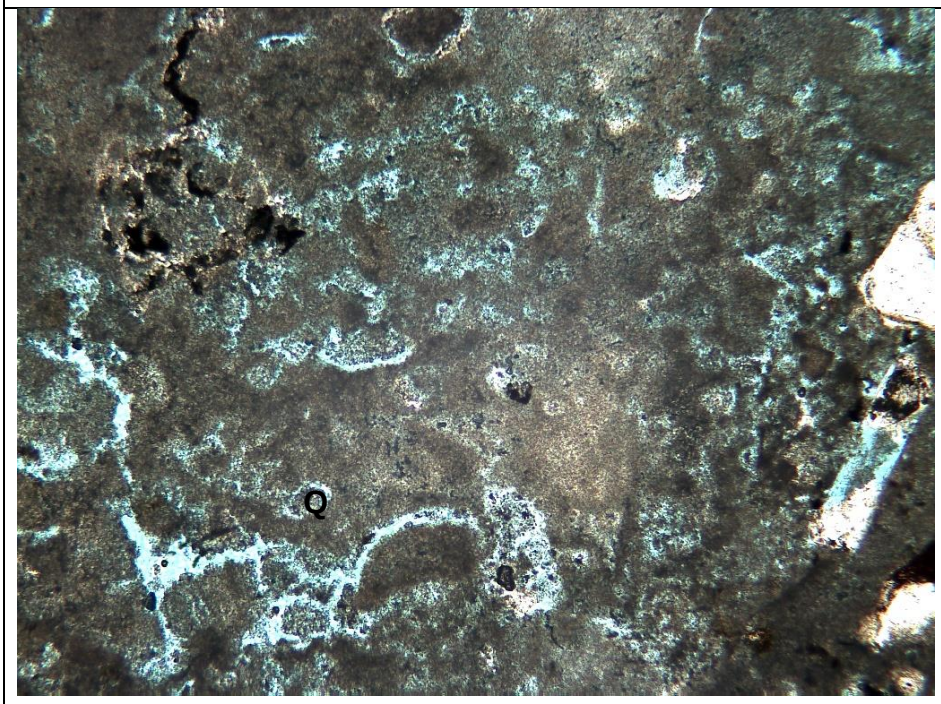


Plate 6. Thin section of the sample under plane polarised light. Pore spaces are highlighted in bright blue, while areas of dark/dull blue indicate the lime binder that has absorbed some of the blue dye). Some lime inclusions show a faint relic core and a small belite cluster. The clinker is not observed in the paste/binder; only in the inclusion: this indicates that the mortar itself was non-hydraulic to feebly hydraulic at most, with clinker only locally formed through over burning of limestone.

Field of view: 3.3mm.

ACID DISSOLUTION & FILTRATION

PROCEDURE	OBSERVATIONS/COMMENTS	
DISSOLUTION OF BINDER USING 10% HCl	On addition of the acid to the powdered sample there was a moderate reaction producing a moderate amount of steam and foam. The reaction slowed after 5 mins but was still producing bubbles but the volume of steam was reduced. This shows a moderate to high free lime content.	
FILTRATION	GRADE: 20	PAPER TYPE: Whatman Type 41

CONSTITUENTS OF ANALYSIS SAMPLE

MATERIAL	WEIGHT (g)	COMMENTS
A: DRY WEIGHT OF ANALYSIS SAMPLE	38.94	Mass of sample analysed (before acid digestion).
B: DRY WEIGHT OF ALL INSOLUBLES	18.71	Insoluble residue recovered after acid digestion (before sieving).
C: DRY WEIGHT OF INSOLUBLE BINDER	0.00	Determined from microscopic examination of filter residue (presence of insoluble hydraulic components can be confirmed by XRD analysis).
D: (B-C) DRY WEIGHT OF AGGREGATE	18.71	Corrected for retention of hydraulic components or other non-soluble reaction products.
E: (A-D) DRY WEIGHT OF LIME	20.23	Including insoluble binder where present.
MOISTURE CONTENT (%)	1.39	Based on mass of sample before and after drying.
OTHER	-	Gypsum and other non-binder related contaminants or reaction products.

AGGREGATE GRADING & CHARACTERISATION

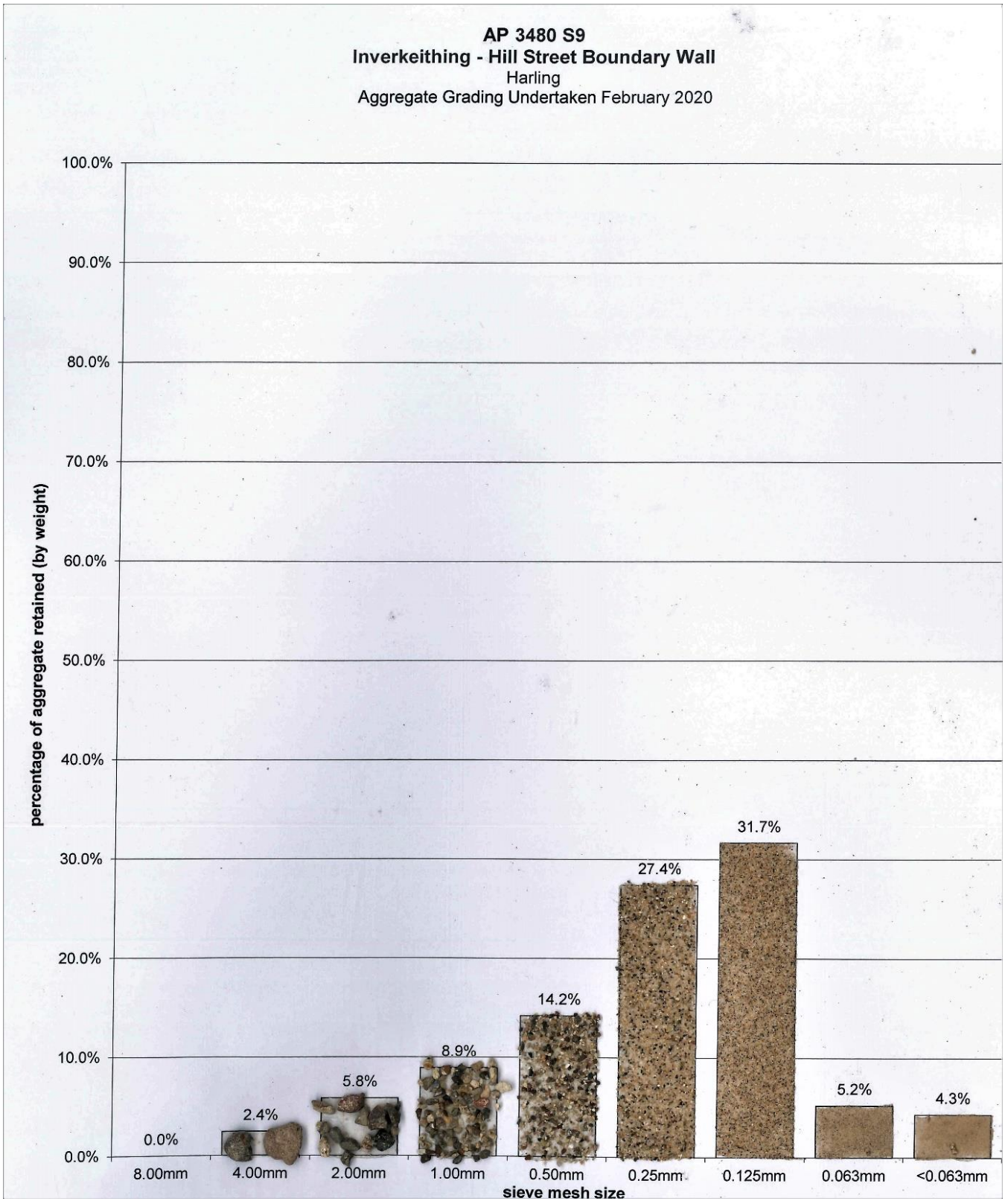
SIEVE PERFORATION SIZE*	AGGREGATE RETAINED (g)	UNDISSOLVED BINDER (%)	CORRECTED AGGREGATE WEIGHT (g)	% OF AGGREGATE	COMMENTS
8mm	0.00	0	0.00	0.0	
4mm	0.43	0	0.43	2.4	Sub-angular to sub-angular well weathered lithic fragments, shell fragments and sub-rounded, sub-spherical quartz grains
2mm	1.04	0	1.04	5.8	As above
1mm	1.59	0	1.59	8.9	As above
500µm	2.53	0	2.53	14.2	As above
250µm	4.88	0	4.88	27.4	As above
125µm	5.64	0	5.64	31.7	Predominantly composed of angular – sub-angular quartz grains, cloudy, glassy, grey and orange/buff tinted and weathered lithic fragments
63µm	0.93	0	0.93	5.2	As above with indiscernible silt and clay.
< 63µm including filter residue	0.77	0	0.77	4.3	As above with indiscernible silt and clay.

***Sieve perforation sizes correspond to those stated in BS EN 1015.1:1999**

The aggregate isolated from this sample is moderately well graded and aggregate is retained from sieve size 4mm down with the highest percentage of grains being retained in sieve mesh 0.125mm with 31.7%. Well weathered lithic fragments, occasional shell fragments and sub angular quartz make up the courser fractions. Smaller fractions are composed predominately of angular to sub-angular quartz grains and the buff/orange/cream tinted grains give the sand its overall pale brown colour. See aggregate profile below.

Because sand and gravel aggregates are ultimately derived from the weathering of solid rock, most aggregates contain course grained rock fragments and finer mineral grains. Physical weathering breaks down the rock fragments within the aggregate into the constituent minerals, resulting in smaller and rounder particles; chemical weathering breaks down unstable minerals, such as feldspars resulting in the formation of clay, which may be washed away. Both weathering processes eventually result in the formation of quartz-rich sand.

Aggregate Profile of the Aggregate Separated from the Mortar Sample



AGGREGATE MATCHING

The closest commercially available matching aggregate, from the SLCT Sands and Aggregates Database taking into account location, grading, grain size, colour and texture is Building Sand from Lomond Quarry (see aggregate profile below). This sand has been retained from sieve mesh size 4mm down, with the highest percentage of grains being retained from sieve mesh size 0.125mm with 40.7%. It is predominantly medium to fine grained with a uni-modal grain size distribution, lithic fragments give a slightly darker colour and a more buff colour is due to the silts and clays at finer fractions with quartz grains present throughout.

An alternative aggregate match is Building Sand from Melville Gates Quarry (see aggregate profile below). This sand has been retained from sieve mesh size 4mm down, with the highest percentage of grains being retained from sieve mesh size 0.250mm with 41.5%. It is well graded with a uni-modal grain size distribution, lithic fragments give a slightly darker colour and a more buff colour is due to the silts and clays at finer fractions with quartz grains present throughout. This sand has a slightly different grainsize distribution to the analysed sample but it is well graded.

Contact details for these quarries are listed below.

Skene Group,
Lomond Quarry,
Balsillie Farm,
Falkland Hills Road,
Leslie,
Fife
KY6 3HD
Tel.: 01592 741 590

Angle Park Sand & Gravel Co. Ltd.,
Melville Gates Quarry,
Ladybank,
Cupar,
Fife
KY7 7RF
Tel.: 01337 830 303

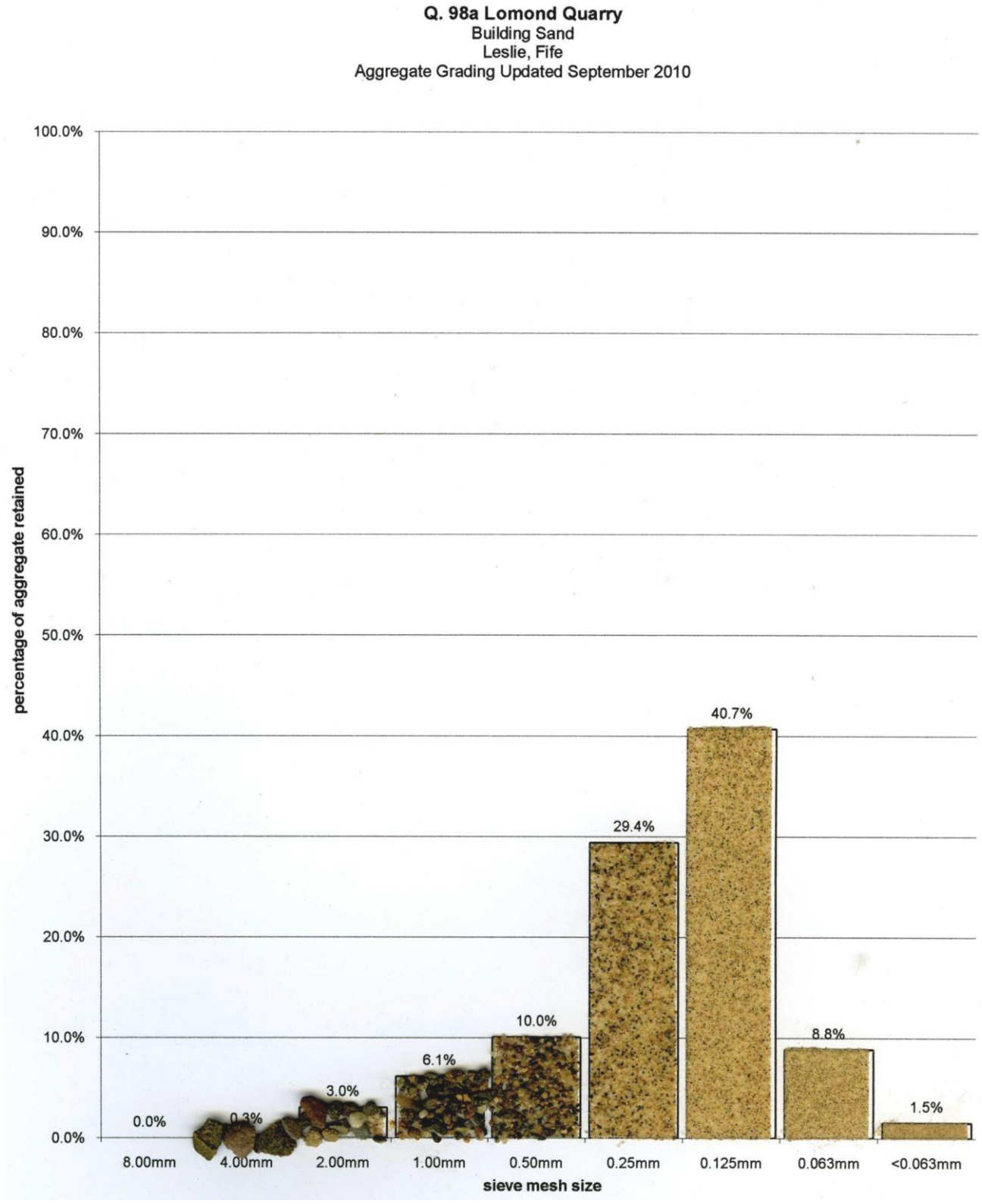
However, the named source(s) is/are not the only potentially suitable source(s) available, but is/are the closest, with respect to visual characteristics and physical properties, on the basis of the work carried out to date, on the sample submitted to examination.

The currently available aggregate samples held in the Scottish Lime Centre Trust's Aggregates Database are provided by the individual quarries/operators and therefore we have to assume that they are representative of the aggregate being produced at the time of receipt of the sample. As with all quarries the actual properties of the aggregate available will be dependent on the area being worked at any given time and it is, therefore, always prudent to obtain samples of the current production for comparison with the aggregate to be matched, prior to ordering supplies for a particular project/application.

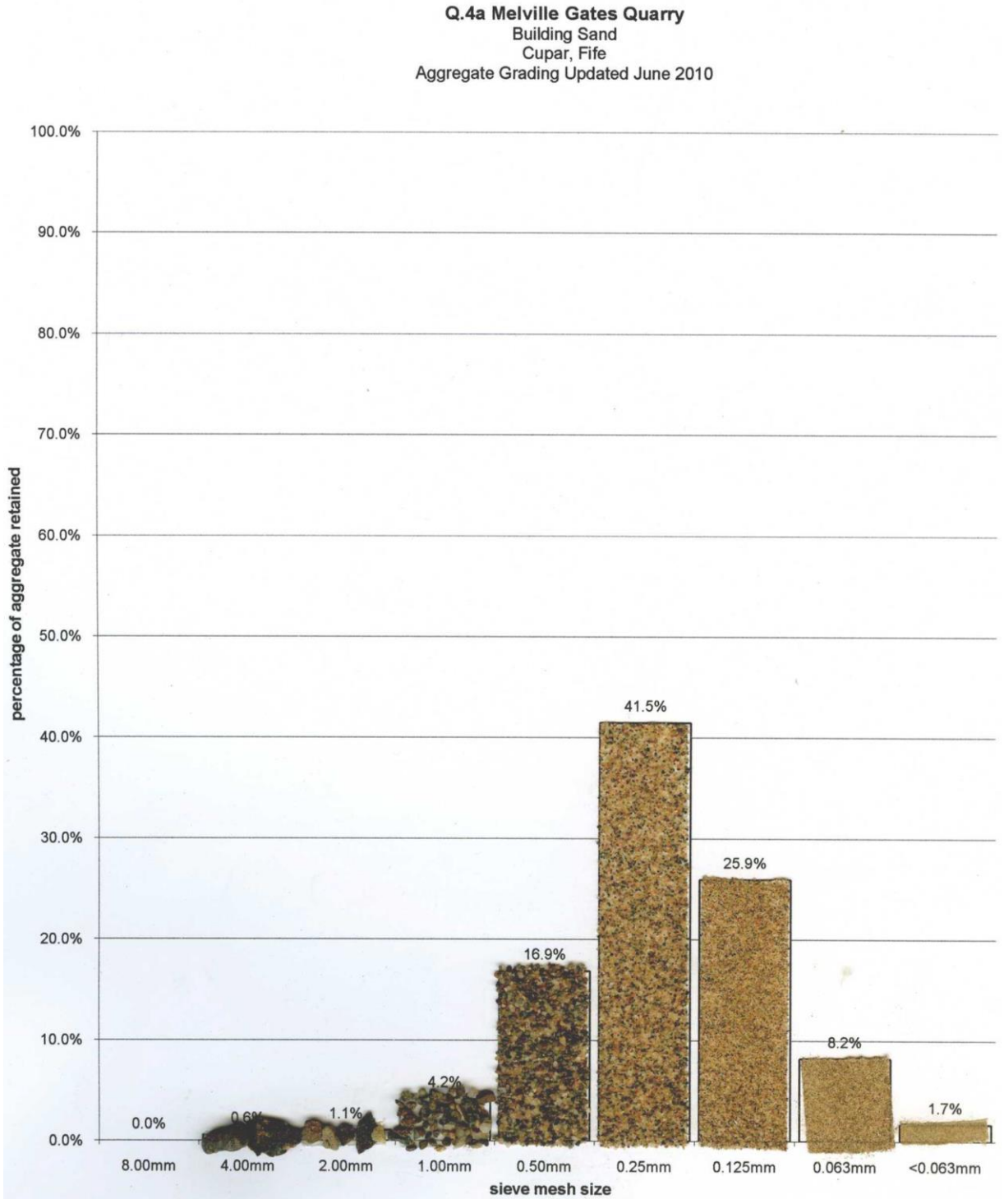
Quarries can change hands, open or close down with a relatively high frequency and therefore the source(s) identified above may become unavailable with no notice. If you are unable to obtain one of the above aggregates within 6 months of us completing this report then we will identify a new source free of charge (after this time period a charge will be incurred).

***If ordered please say that the aggregate was identified by the Scottish Lime Centre Trust.**

Aggregate Profile of the closest Matching Currently Available Aggregate: Building Sand, Lomond Quarry



Aggregate Profile of an Alternate Matching Currently Available Aggregate: Building Sand, Melville Gates Quarry



PROPORTIONS OF ANALYSIS SAMPLE

The sample proportions give the relative weights of aggregate and carbonated or set lime, unless otherwise stated.

LIME	:	AGGREGATE
1	:	0.9

PROBABLE ORIGINAL MIX

The original mix gives the relative weights of the mortar constituents as mixed on site and before carbonation. From the nature of the binding matrix of the mortar sample and from information gained from the analysis, it is probable that the mortar was made up from a non-hydraulic to feebly hydraulic quicklime.

1 PART NON-HYDRAULIC TO FEEBLY HYDRAULIC QUICKLIME	**:**	**1.5 PARTS AGGREGATE (BY WEIGHT)**

Please note that the proportions given above relate to the sample supplied, this is not a specification.

If a repair specification is required please contact us, and we can arrange for one of our surveyors/consultants to visit and inspect the building/structure, evaluate the relevant requirements, and subsequently provide recommendations and/or specifications for construction and repair work.

COMMENTS

The lime inclusions in the sample examined appear, in part at least, to have behaved as binder. They form an integral part of the mortar fabric and have not, as commonly seen in lime based mortars, simply acted as aggregate material.

There was no evidence from the thin section analysis of any pozzolan additives or hydraulic components in the mortar. There is no clinker observed in the paste/binder; it is only found in fine clusters within lime inclusion: this indicates that the mortar itself was non-hydraulic to feebly hydraulic at most, with clinker only locally formed through over burning of limestone.

The binder is fully carbonated, and lime inclusions are sub-rounded to irregular in shape and commonly exhibit relic cores, and have the appearance typical of having been placed as a well slaked quicklime in a "hot mixed lime" mortar.

The grading of the aggregate, along with the presence of shell fragments, suggests a local ‘as dug’ source, likely from the mouth of the river.

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MORTAR ANALYSIS REPORT

AP 3480
Inverkeithing Town House, Inverkeithing Stone and Slate Audit

Sample 5

Construction mortar

SITE	Inverkeithing Town House, Inverkeithing, Fife
CLIENT	Fife Historic Buildings Trust
DATE SAMPLE RECEIVED	11/12/2019
ANALYSIS DATES	11/12/2019 – 20/01/2020
ANALYSIS, INTERPRETATION & REPORT BY	Dr Katie Strang and Roz Artis
CLIENT REQUIREMENTS	Standard Mortar Analysis
STRUCTURE DATE	1770
STRUCTURE TYPE	Town House
MORTAR DATING	1770
LOCATION/ FUNCTION IN BUILDING	Construction mortar from back elevation
CONDITION OF SAMPLE RECEIVED	The sample received consisted of a bag containing intact pieces of mortar plus fines. Size of largest piece = 16.11 mm x 11.37 mm x 4.62 mm Total mass of sample received = 96.87 grams

SUMMARY AND INTERPRETATION OF ANALYSIS RESULTS

The mortar appears to consist of a non-hydraulic to feebly hydraulic lime binder, most likely prepared as a ‘‘dry hydrate’. To confirm the binder type and strength, further analysis by thin section (petrography) and X-Ray Diffraction would be required (in this sample the strength of binder is inferred from the hardness of the specimens examined). The colour of the mortar assessed against the Munsell Soil Colour Charts was found to be to 10YR 8/1 ‘white’ to 10YR 8/2 ‘very pale brown’.

The mix ratio of the sample is approximately 1 part non-hydraulic to feebly hydraulic dry hydrate to 0.85 parts aggregate (by volume).

This mortar analysis report is NOT intended as a repair specification. Details of repair specifications based on information from this report should also take account of prevailing site conditions, including stone type and condition, location and function of the new mortar, building details, exposure, seasonal working etc.

ANALYTICAL PROCEDURES

The selected sample of material was dried to a constant weight and examined under a binocular microscope at x40 magnification. Degree of carbonation of the sample was determined using phenolphthalein indicator, which will react with any uncarbonated lime.

An assessment of the binder type was made by evaluating the physical characteristics of the mortar based on our knowledge, experience and understanding of materials.

Application of 10% Hydrochloric acid to the sample resulted in dissolution of the binder enabling relative proportions of lime (and gypsum) to aggregate to be determined; where appropriate, proportions of insoluble binder were determined and factored into this calculation. Subsequent aggregate characterisation was undertaken by means of dry sieve analysis and microscopic analysis.

The analysis results and interpretations made from it provide information on the composition and characteristics of the mortar sample(s) received by the SLCT laboratory. **Provided the sample was representative of the mortar generally**, the analysis will give a reasonable indication of the original materials and provide a **basis for specification** of repair mortars. If more detailed information is required (for example, for purposes of historic research) more sophisticated analytical procedures can be undertaken.

MORTAR EXAMINATION AND ANALYSIS

Plate 1. The total sample received (dish c.160mm diameter).

Plate 2. Showing a fragment of disrupted mortar. Scale is in mm.

PROCEDURE	OBSERVATIONS
PRELIMINARY VISUAL ANALYSIS OF SAMPLE	The sample was received as a fully carbonated disrupted mortar. The mortar was very friable and easy to disrupt, and could be powdered with ease. Fines consisted of silt and individual aggregate grains. There was no evidence of lime inclusions or burnt fuel/coal fragments in this sample. The phenolphthalein indicator test confirmed that the mortar was fully carbonated whilst a water droplet test confirmed that the mortar was porous as the droplets were rapidly absorbed and the water diffused throughout the mortar.
EXAMINATION OF PREPARED SAMPLE BY BINOCULAR MICROSCOPE (X40 MAGNIFICATION)	The colour of the mortar assessed against the Munsell Soil Colour Charts was found to be to 10YR 8/1 'white' to 10YR 8/2 'very pale brown'. The surface of the intact appeared porous and had a granular texture, contained an abundance of air voids, some of which contained linings of calcite as secondary products, soiling and organic matter, all indicating that water percolation through the mortar had occurred. Overall the aggregate appears quite coarse grained, with larger well weathered and grey/dark in lithic fragments appear to make up the courser aggregate fractions. The finer fractions of aggregate appear to consist mainly of sub-angular to angular quartz grains with a buff/orange/grey tint.

ACID DISSOLUTION & FILTRATION

PROCEDURE	OBSERVATIONS/COMMENTS	
DISSOLUTION OF BINDER USING 10% HCl	On addition of the acid to the powdered sample there was a moderate reaction producing a moderate amount of steam and foam. The reaction slowed after 5 mins but was still producing bubbles but the volume of steam was reduced. This shows a moderate to high free lime content.	
FILTRATION	GRADE: 20	PAPER TYPE: Whatman Type 41

CONSTITUENTS OF ANALYSIS SAMPLE

MATERIAL	WEIGHT (g)	COMMENTS
A: DRY WEIGHT OF ANALYSIS SAMPLE	46.67	Mass of sample analysed (before acid digestion).
B: DRY WEIGHT OF ALL INSOLUBLES	29.52	Insoluble residue recovered after acid digestion (before sieving).
C: DRY WEIGHT OF INSOLUBLE BINDER	0.00	Determined from microscopic examination of filter residue (presence of insoluble hydraulic components can be confirmed by XRD analysis).
D: (B-C) DRY WEIGHT OF AGGREGATE	29.52	Corrected for retention of hydraulic components or other non-soluble reaction products.
E: (A-D) DRY WEIGHT OF LIME	17.15	Including insoluble binder where present.
MOISTURE CONTENT (%)	3.53	Based on mass of sample before and after drying.
OTHER	-	Gypsum and other non-binder related contaminants or reaction products.

AGGREGATE GRADING & CHARACTERISATION

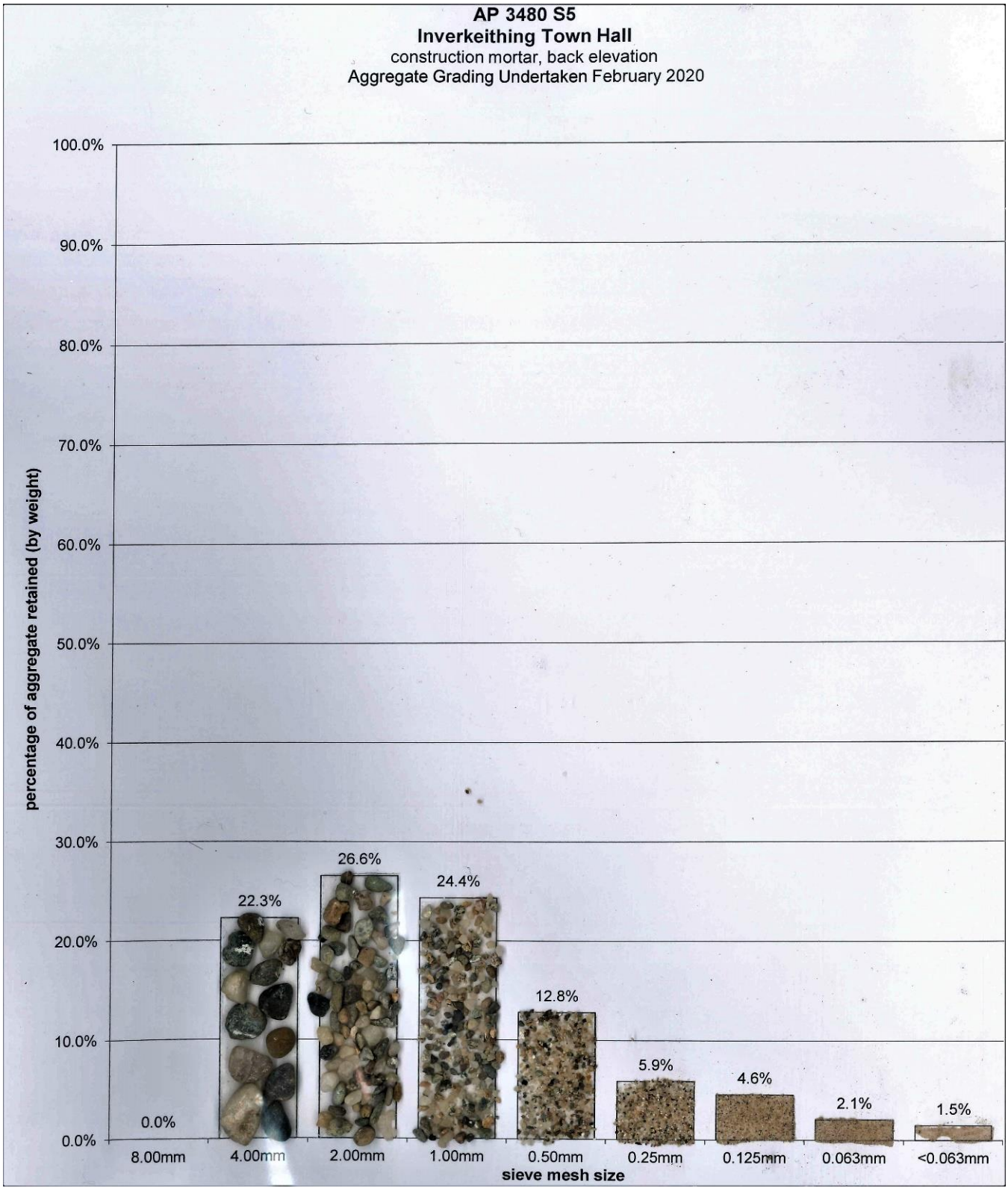
SIEVE PERFORATION SIZE*	AGGREGATE RETAINED (g)	UNDISSOLVED BINDER (%)	CORRECTED AGGREGATE WEIGHT (g)	% OF AGGREGATE	COMMENTS
8mm	0.00	0	0.00	0.0	
4mm	6.31	0	6.31	22.3	Sub-angular to sub-angular well weathered lithic fragmentsand sub-rounded, sub-spherical quartz grains
2mm	7.52	0	7.52	26.6	Predominantly composed of angular – sub-angular quartz grains, cloudy, glassy, grey and orange/buff tinted and weathered lithic fragments
1mm	6.89	0	6.89	24.4	As above
500µm	3.62	0	3.62	12.8	As above
250µm	1.66	0	1.66	5.9	As above
125µm	1.29	0	1.29	4.6	As above
63µm	0.58	0	0.58	2.1	As above with indiscernible silt and clay.
< 63µm including filter residue	0.42	0	0.42	1.5	As above with indiscernible silt and clay.

***Sieve perforation sizes correspond to those stated in BS EN 1015.1:1999**

The aggregate isolated from this sample is moderately well graded and aggregate is retained from sieve size 4mm down with the highest percentage of grains being retained in sieve mesh 2mm with 26.6%. Well weathered lithic fragments and sub angular quartz make up the courser fractions. Smaller fractions are composed predominately of angular to sub-angular quartz grains and the buff/orange/cream tinted grains give the sand its overall pale brown colour. See aggregate profile below.

Because sand and gravel aggregates are ultimately derived from the weathering of solid rock, most aggregates contain course grained rock fragments and finer mineral grains. Physical weathering breaks down the rock fragments within the aggregate into the constituent minerals, resulting in smaller and rounder particles; chemical weathering breaks down unstable minerals, such as feldspars resulting in the formation of clay, which may be washed away. Both weathering processes eventually result in the formation of quartz-rich sand.

Aggregate Profile of the Aggregate Separated from the Mortar Sample



AGGREGATE MATCHING

The closest commercially available matching aggregate, from the SLCT Sands and Aggregates Database taking into account location, grading, grain size, colour and texture is Concrete Sand from Melville Gates Quarry (see aggregate profile below). This sand has been retained from sieve mesh size 4mm down, with the highest percentage of grains being retained from sieve mesh size 0.250mm with 25.2%. It is predominantly medium grained with a uni-modal grain size distribution, lithic fragments give a slightly darker colour and a more buff colour is due to the silts and clays at finer fractions with quartz grains present throughout.

An alternative aggregate match is Concrete Sand from Lomond Quarry (see aggregate profile below). This sand has been retained from sieve mesh size 4mm down, with the highest percentage of grains being retained from sieve mesh size 0.125mm with 26.7%. It is well graded with a uni-modal grain size distribution, lithic fragments give a slightly darker colour and a more buff colour is due to the silts and clays at finer fractions with quartz grains present throughout.

Contact details for these quarries are listed below, both are from Fife Silica Sands.

Angle Park Sand & Gravel Co Ltd,
Melville Gates Quarry,
Melville Gates,
Ladybank,
Cupar
Fife
KY15 7RF

Tel.: 01337 830303

Skene Group,
Lomond Quarry,
Balsillie Farm,
Falkland Hills Road,
Leslie,
Fife
KY6 3HD

Tel.: 01592 741 590

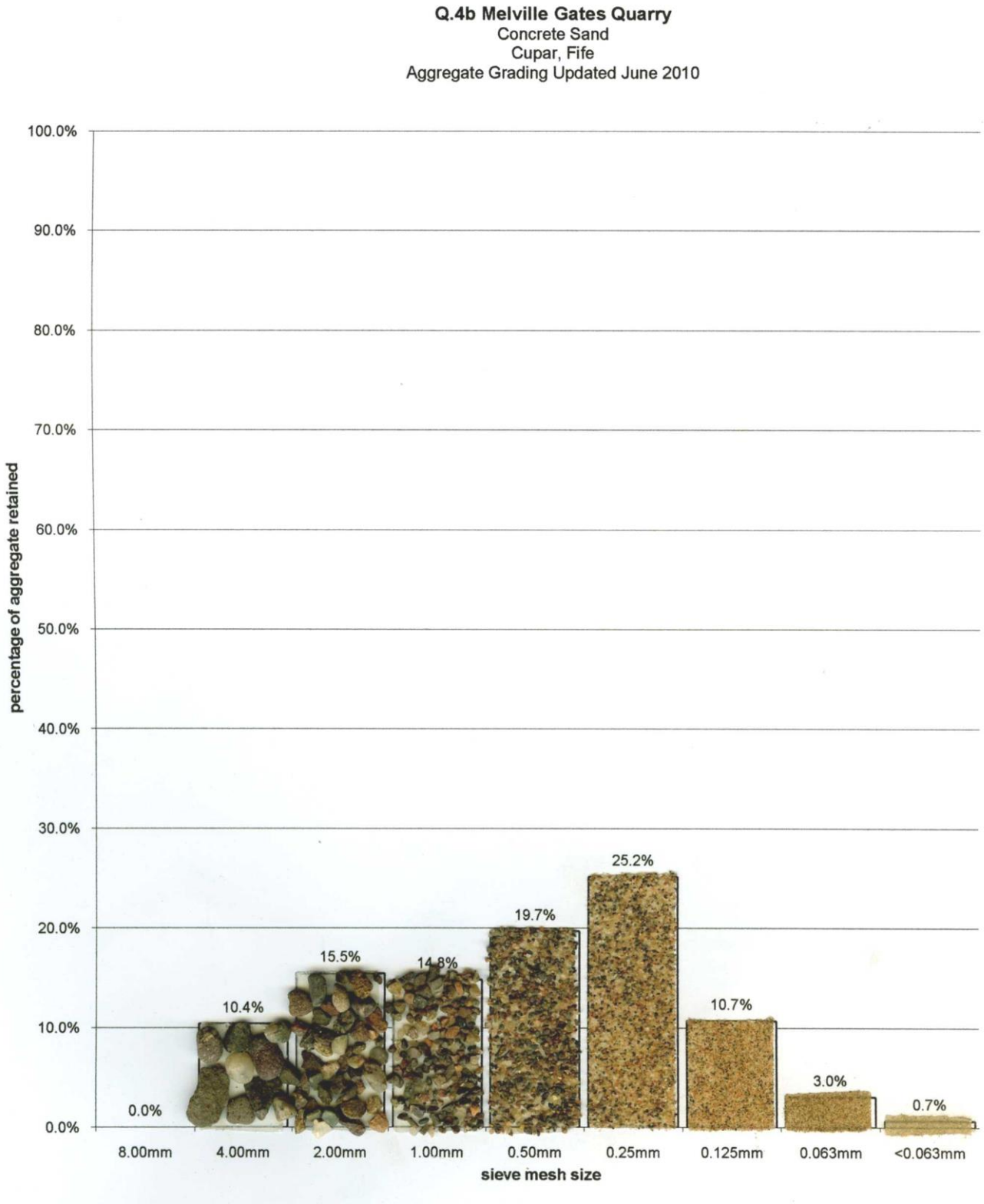
However, the named source(s) is/are not the only potentially suitable source(s) available, but is/are the closest, with respect to visual characteristics and physical properties, on the basis of the work carried out to date, on the sample submitted to examination.

The currently available aggregate samples held in the Scottish Lime Centre Trust's Aggregates Database are provided by the individual quarries/operators and therefore we have to assume that they are representative of the aggregate being produced at the time of receipt of the sample. As with all quarries the actual properties of the aggregate available will be dependent on the area being worked at any given time and it is, therefore, always prudent to obtain samples of the current production for comparison with the aggregate to be matched, prior to ordering supplies for a particular project/application.

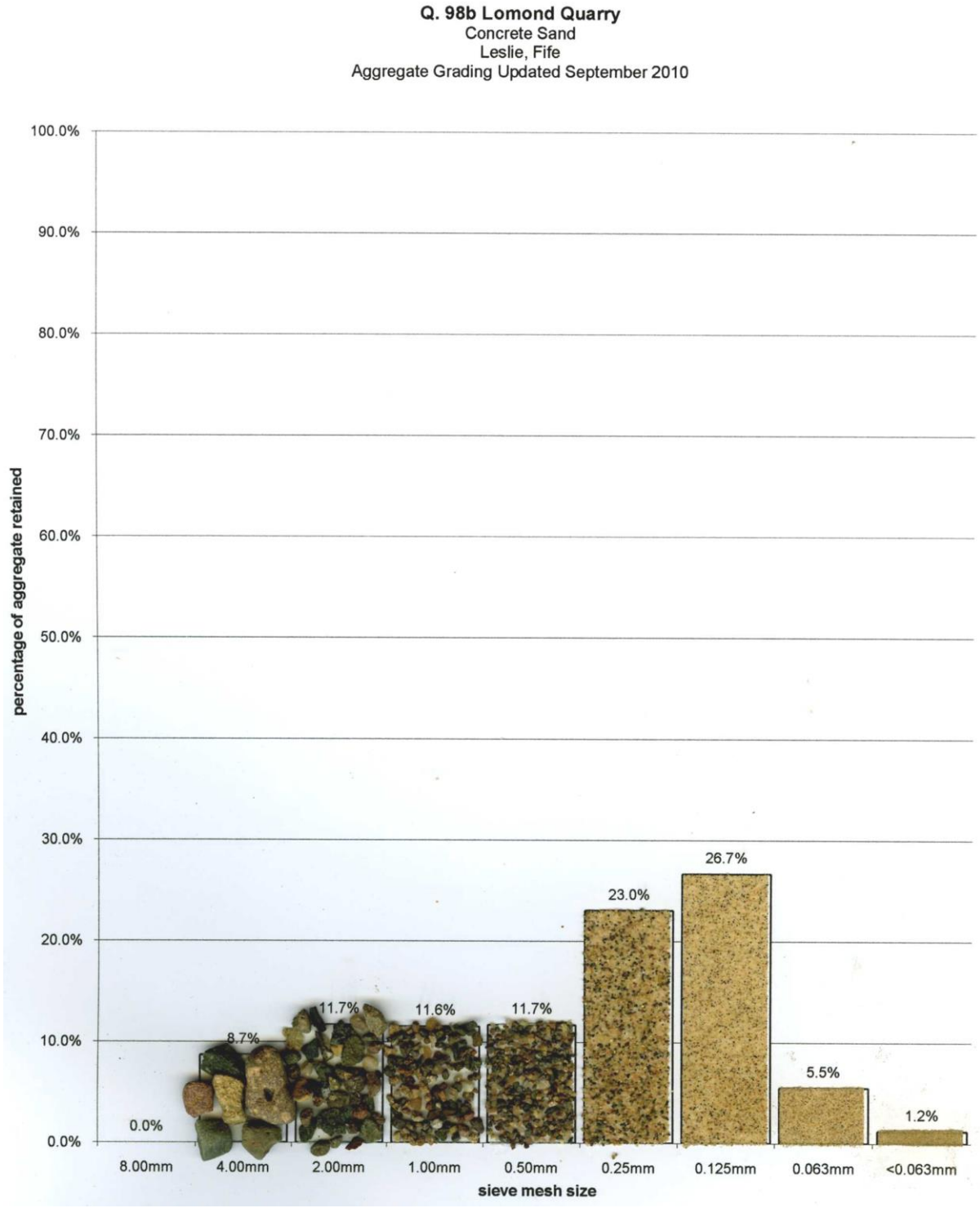
Quarries can change hands, open or close down with a relatively high frequency and therefore the source(s) identified above may become unavailable with no notice. If you are unable to obtain one of the above aggregates within 6 months of us completing this report then we will identify a new source free of charge (after this time period a charge will be incurred).

***If ordered please say that the aggregate was identified by the Scottish Lime Centre Trust.**

Aggregate Profile of the closest Matching Currently Available Aggregate: Concrete Sand, Melville Gates Quarry



Aggregate Profile of an Alternate Matching Currently Available Aggregate: Concrete Sand, Lomond Quarry



PROPORTIONS OF ANALYSIS SAMPLE

The sample proportions give the relative weights of aggregate and carbonated or set lime, unless otherwise stated.

LIME	:	AGGREGATE
1	:	1.7

PROBABLE ORIGINAL MIX

The original mix gives the relative weights of the mortar constituents as mixed on site and before carbonation. From the nature of the binding matrix of the mortar sample and from information gained from the analysis, it is probable that the mortar was made up from a non-hydraulic to feebly hydraulic dry hydrate.

1 PART NON-HYDRAULIC TO FEEBLY HYDRAULIC DRY HYDRATE	**:**	**2.2 PARTS AGGREGATE (BY WEIGHT)**

Please note that the proportions given above relate to the sample supplied, this is not a specification.

If a repair specification is required please contact us, and we can arrange for one of our surveyors/consultants to visit and inspect the building/structure, evaluate the relevant requirements, and subsequently provide recommendations and/or specifications for construction and repair work.

SCOTTISH LIME CENTRE TRUST

Charlestown Workshops
2 Rocks Road
Charlestown
Fife
KY11 3EN
T: + 44 (0)1383 872722
F: + 44 (0)1383 872744

MORTAR ANALYSIS REPORT

AP 3480
Hill Street Boundary Wall, Inverkeithing Stone and Slate Audit

Sample 8

Construction mortar

SITE	Hill Street Boundary Wall, Inverkeithing, Fife
CLIENT	Fife Historic Buildings Trust
DATE SAMPLE RECEIVED	11/12/2019
ANALYSIS DATES	11/12/2019 – 20/01/2020
ANALYSIS, INTERPRETATION & REPORT BY	Dr Katie Strang and Roz Artis
CLIENT REQUIREMENTS	Standard Mortar Analysis
STRUCTURE DATE	? mid 19th century or earlier
STRUCTURE TYPE	Boundary Wall
MORTAR DATING	? original
LOCATION/ FUNCTION IN BUILDING	Construction mortar from RHS of boundary wall
CONDITION OF SAMPLE RECEIVED	The sample received consisted of a bag containing intact pieces of mortar plus fines. Size of largest piece = 89.21 mm x 65.14 mm x 32.22 mm Total mass of sample received = 133.46 grams

SUMMARY AND INTERPRETATION OF ANALYSIS RESULTS

The mortar appears to consist of a non-hydraulic to feebly hydraulic lime binder, most likely prepared as a 'hot mixed' lime mortar by slaking quicklime and sand together in one operation. To confirm the binder type and strength, further analysis by thin section (petrography) and X-Ray Diffraction would be required (in this sample the strength of binder is inferred from the hardness of the specimens examined). The colour of the mortar assessed against the Munsell Soil Colour Charts was found to be to 10YR 8/1 'white' to 10YR 8/2 'very pale brown'.

The mix ratio of the sample is approximately 1 part non-hydraulic to feebly hydraulic quicklime to 0.65 parts aggregate (by volume).

This mortar analysis report is NOT intended as a repair specification. Details of repair specifications based on information from this report should also take account of prevailing site conditions, including stone type and condition, location and function of the new mortar, building details, exposure, seasonal working etc.

ANALYTICAL PROCEDURES

The selected sample of material was dried to a constant weight and examined under a binocular microscope at x40 magnification. Degree of carbonation of the sample was determined using phenolphthalein indicator, which will react with any uncarbonated lime.

An assessment of the binder type was made by evaluating the physical characteristics of the mortar based on our knowledge, experience and understanding of materials.

Application of 10% Hydrochloric acid to the sample resulted in dissolution of the binder enabling relative proportions of lime (and gypsum) to aggregate to be determined; where appropriate, proportions of insoluble binder were determined and factored into this calculation. Subsequent aggregate characterisation was undertaken by means of dry sieve analysis and microscopic analysis.

The analysis results and interpretations made from it provide information on the composition and characteristics of the mortar sample(s) received by the SLCT laboratory. **Provided the sample was representative of the mortar generally**, the analysis will give a reasonable indication of the original materials and provide a **basis for specification** of repair mortars. If more detailed information is required (for example, for purposes of historic research) more sophisticated analytical procedures can be undertaken.

MORTAR EXAMINATION AND ANALYSIS

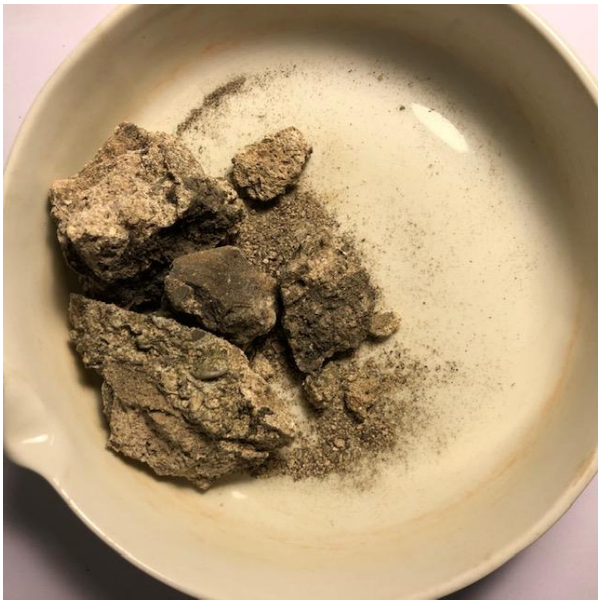


Plate 1. The total sample received (dish c.160mm diameter).

Plate 2. Showing a fragment of disrupted mortar. Scale is in mm.

PROCEDURE	OBSERVATIONS
PRELIMINARY VISUAL ANALYSIS OF SAMPLE	The sample was received as a fully carbonated intact piece of mortar plus fines. The sample is weak and requires little pressure to disrupt, and is easy to powder. There were large irregularly shaped, cracked lime inclusions throughout the sample. There was also an abundance of large angular coal fragments throughout. The phenolphthalein indicator test confirmed that the mortar was fully carbonated whilst a water droplet test confirmed that the mortar was porous as the droplets were rapidly absorbed and the water diffused throughout the mortar.
EXAMINATION OF PREPARED SAMPLE BY BINOCULAR MICROSCOPE (X40 MAGNIFICATION)	The colour of the mortar assessed against the Munsell Soil Colour Charts was found to be 10YR 8/2 ‘very pale brown’. The surface of the sample appeared porous and had a granular texture and the mortar appeared binder rich. Larger lithic fragments appear to make up the courser aggregate fractions, and are well weathered and the majority are igneous or sedimentary in origin. The finer fractions of aggregate appear to consist mainly of sub-angular to angular quartz grains with a buff/orange/grey tint. The mortar showed voiding and evidence of calcite re-precipitation, suggesting moisture movement through the mortar.

ACID DISSOLUTION & FILTRATION

PROCEDURE	OBSERVATIONS/COMMENTS	
DISSOLUTION OF BINDER USING 10% HCl	On addition of the acid to the powdered sample there was a moderate reaction producing a moderate amount of steam and foam. The reaction slowed after 5 mins but was still producing bubbles but the volume of steam was reduced. This shows a moderate to high free lime content.	
FILTRATION	GRADE: 20	PAPER TYPE: Whatman Type 41

CONSTITUENTS OF ANALYSIS SAMPLE

MATERIAL	WEIGHT (g)	COMMENTS
A: DRY WEIGHT OF ANALYSIS SAMPLE	62.33	Mass of sample analysed (before acid digestion).
B: DRY WEIGHT OF ALL INSOLUBLES	36.67	Insoluble residue recovered after acid digestion (before sieving).
C: DRY WEIGHT OF INSOLUBLE BINDER	0.00	Determined from microscopic examination of filter residue (presence of insoluble hydraulic components can be confirmed by XRD analysis).
D: (B-C) DRY WEIGHT OF AGGREGATE	36.67	Corrected for retention of hydraulic components or other non-soluble reaction products.
E: (A-D) DRY WEIGHT OF LIME	25.66	Including insoluble binder where present.
MOISTURE CONTENT (%)	2.71	Based on mass of sample before and after drying.
OTHER	-	Gypsum and other non-binder related contaminants or reaction products.

AGGREGATE GRADING & CHARACTERISATION

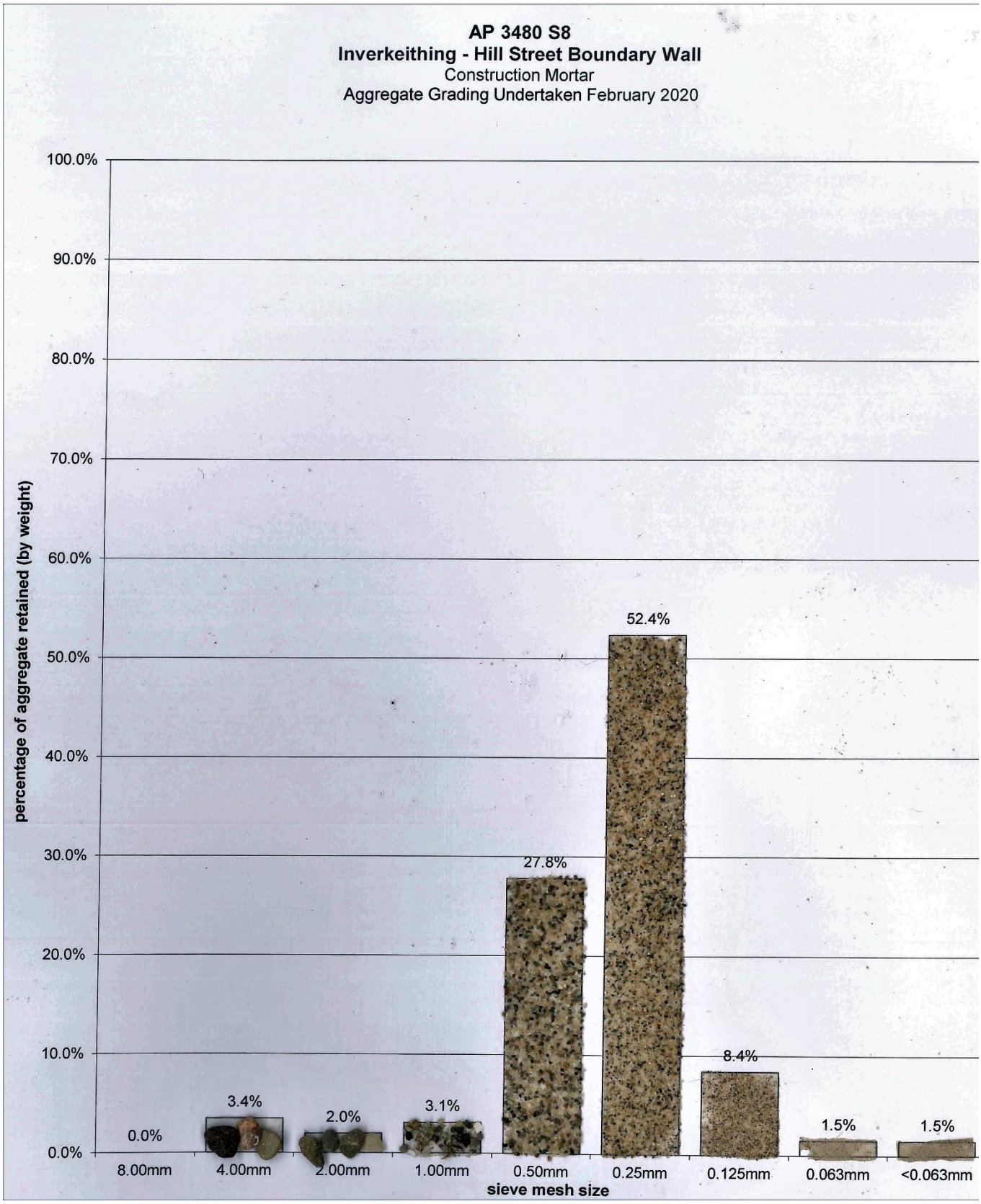
SIEVE PERFORATION SIZE*	AGGREGATE RETAINED (g)	UNDISSOLVED BINDER (%)	CORRECTED AGGREGATE WEIGHT (g)	% OF AGGREGATE	COMMENTS
8mm	0.00	0	0.00	0.0	
4mm	1.18	0	1.18	3.4	Sub-angular to sub-angular well weathered lithic fragmentsand sub-rounded, sub-spherical quartz grains
2mm	0.67	0	0.67	2.0	Predominantly composed of angular – sub-angular quartz grains, cloudy, glassy, grey and orange/buff tinted and weathered lithic fragments
1mm	1.06	0	1.06	3.1	As above
500µm	9.52	0	9.52	27.8	As above
250µm	17.94	0	17.94	52.4	As above
125µm	2.87	0	2.87	8.4	As above
63µm	0.52	0	0.52	1.5	As above with indiscernible silt and clay.
< 63µm including filter residue	0.50	0	0.50	1.5	As above with indiscernible silt and clay.

***Sieve perforation sizes correspond to those stated in BS EN 1015.1:1999**

The aggregate isolated from this sample is poorly to moderately well graded and aggregate is retained from sieve size 4mm down with the highest percentage of grains being retained in sieve mesh 0.250mm with 52.4%. Well weathered lithic fragments and sub angular quartz make up the courser fractions. Smaller fractions are composed predominately of angular to sub-angular quartz grains and the buff/orange/cream tinted grains give the sand its overall pale brown colour. See aggregate profile below.

Because sand and gravel aggregates are ultimately derived from the weathering of solid rock, most aggregates contain course grained rock fragments and finer mineral grains. Physical weathering breaks down the rock fragments within the aggregate into the constituent minerals, resulting in smaller and rounder particles; chemical weathering breaks down unstable minerals, such as feldspars resulting in the formation of clay, which may be washed away. Both weathering processes eventually result in the formation of quartz-rich sand.

Aggregate Profile of the Aggregate Separated from the Mortar Sample



AGGREGATE MATCHING

The closest commercially available matching aggregate, from the SLCT Sands and Aggregates Database taking into account location, grading, grain size, colour and texture is Building Sand from Melville Gates Quarry (see aggregate profile below). This sand has been retained from sieve mesh size 4mm down, with the highest percentage of grains being retained from sieve mesh size 0.250mm with 41.5%. It is predominantly medium to fine grained with a uni-modal grain size distribution, lithic fragments give a slightly darker colour and a more buff colour is due to the silts and clays at finer fractions with quartz grains present throughout.

An alternative aggregate match is Washed Concrete Sand from Temple Quarry (see aggregate profile below). This sand has been retained from sieve mesh size 4mm down, with the highest percentage of grains being retained from sieve mesh size 0.250mm with 26.3%. It is well graded with a uni-modal grain size distribution, lithic fragments give a slightly darker colour and a more buff colour is due to the silts and clays at finer fractions with quartz grains present throughout. This sand has a slightly different grainsize distribution to the analysed sample but it is well graded.

Contact details for these quarries are listed below.

Angle Park Sand & Gravel Co. Ltd.,
Melville Gates Quarry,
Ladybank,
Cupar,
Fife
KY7 7RF

Tel.: 01337 830 303

Cemex,
Temple Quarry,
Guildie Howes Road,
Middleton,
Midlothian
EH23 4QP

Tel. Sales: 0845 155 1806

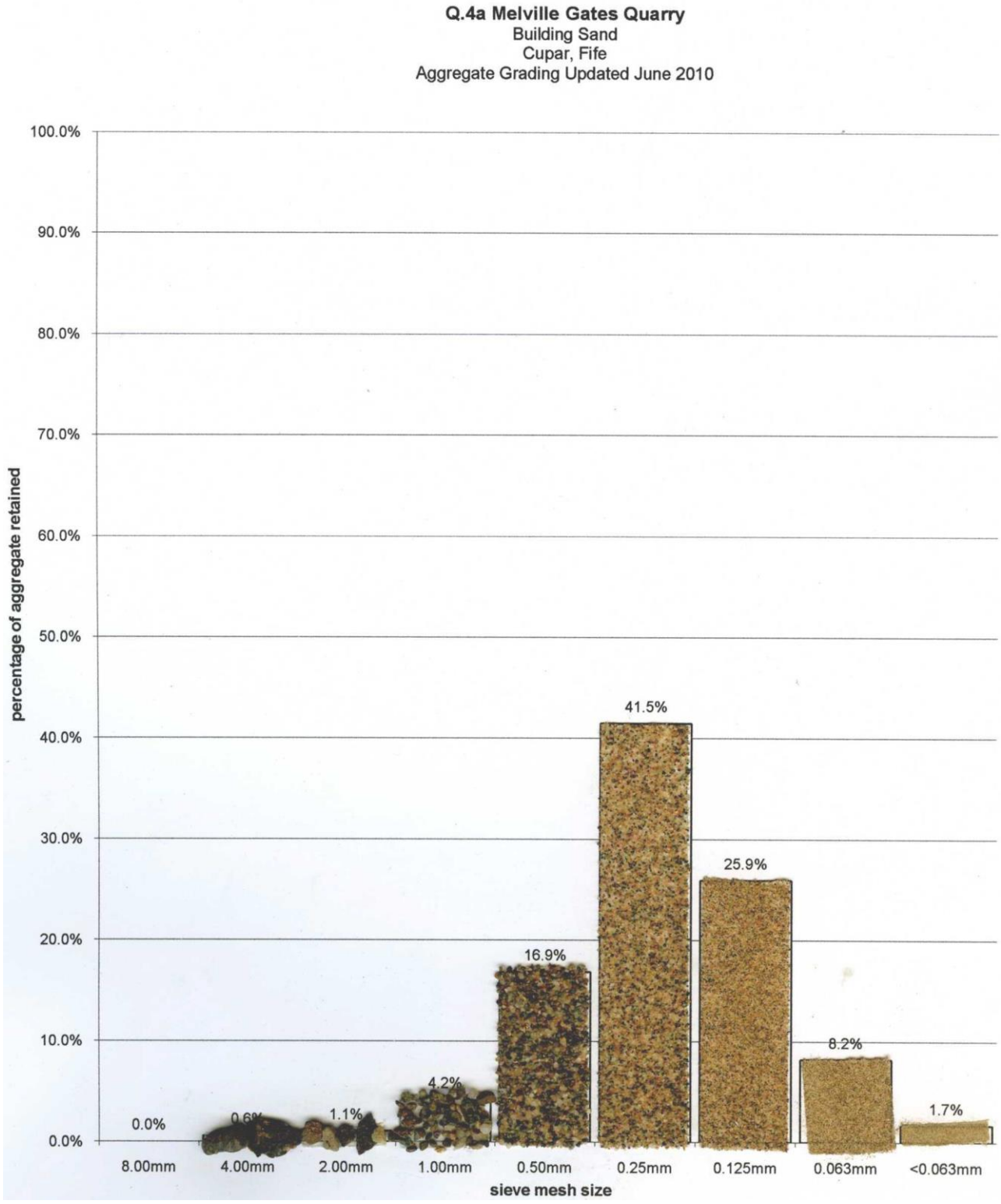
However, the named source(s) is/are not the only potentially suitable source(s) available, but is/are the closest, with respect to visual characteristics and physical properties, on the basis of the work carried out to date, on the sample submitted to examination.

The currently available aggregate samples held in the Scottish Lime Centre Trust's Aggregates Database are provided by the individual quarries/operators and therefore we have to assume that they are representative of the aggregate being produced at the time of receipt of the sample. As with all quarries the actual properties of the aggregate available will be dependent on the area being worked at any given time and it is, therefore, always prudent to obtain samples of the current production for comparison with the aggregate to be matched, prior to ordering supplies for a particular project/application.

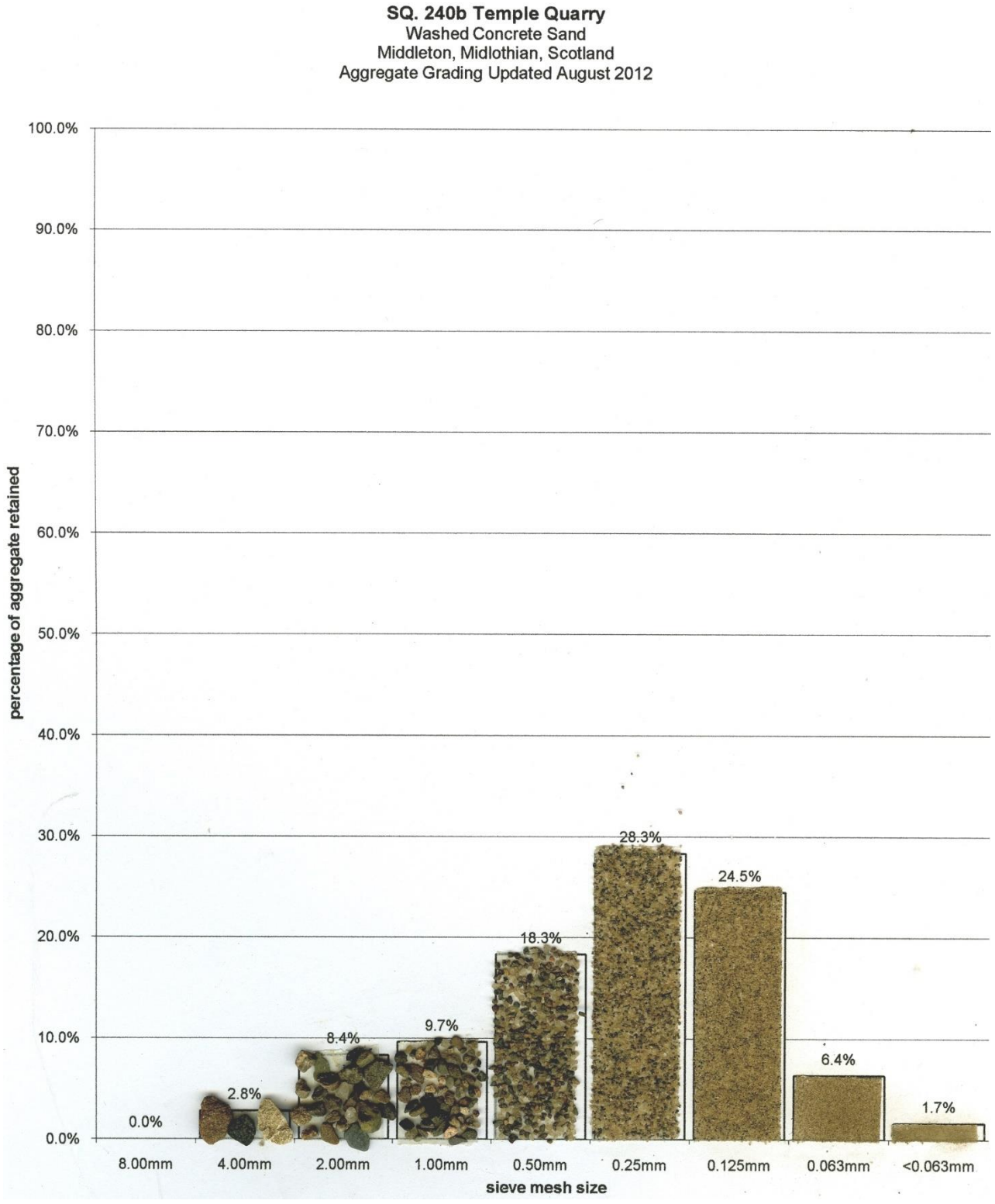
Quarries can change hands, open or close down with a relatively high frequency and therefore the source(s) identified above may become unavailable with no notice. If you are unable to obtain one of the above aggregates within 6 months of us completing this report then we will identify a new source free of charge (after this time period a charge will be incurred).

***If ordered please say that the aggregate was identified by the Scottish Lime Centre Trust.**

Aggregate Profile of the closest Matching Currently Available Aggregate: Building Sand, Melville Gates Quarry



Aggregate Profile of an Alternate Matching Currently Available Aggregate: Washed Concrete Sand, Temple Quarry



PROPORTIONS OF ANALYSIS SAMPLE

The sample proportions give the relative weights of aggregate and carbonated or set lime, unless otherwise stated.

LIME	:	AGGREGATE
1	:	1.4

PROBABLE ORIGINAL MIX

The original mix gives the relative weights of the mortar constituents as mixed on site and before carbonation. From the nature of the binding matrix of the mortar sample and from information gained from the analysis, it is probable that the mortar was made up from a non-hydraulic to feebly hydraulic quicklime.

1 PART NON-HYDRAULIC TO FEEBLY HYDRAULIC QUICKLIME	**:**	**2.3 PARTS AGGREGATE (BY WEIGHT)**

Please note that the proportions given above relate to the sample supplied, this is not a specification.

If a repair specification is required please contact us, and we can arrange for one of our surveyors/consultants to visit and inspect the building/structure, evaluate the relevant requirements, and subsequently provide recommendations and/or specifications for construction and repair work.

SCOTTISH LIME CENTRE TRUST

Charlestown Workshops
2 Rocks Road
Charlestown
Fife
KY11 3EN
T: + 44 (0)1383 872722
F: + 44 (0)1383 872744

MORTAR ANALYSIS REPORT

AP 3480
Bank Street Salon, Inverkeithing Stone and Slate Audit

Sample 11

Construction mortar

SITE	Bank Street Salon, Inverkeithing, Fife
CLIENT	Fife Historic Buildings Trust
DATE SAMPLE RECEIVED	10/12/2019
ANALYSIS DATES	10/12/2019 – 12/03/2020
ANALYSIS, INTERPRETATION & REPORT BY	Dr Katie Strang and Roz Artis
CLIENT REQUIREMENTS	Standard Mortar Analysis
STRUCTURE DATE	? Mid 19th century
STRUCTURE TYPE	Salon and residential
MORTAR DATING	Original?
LOCATION/ FUNCTION IN BUILDING	Construction mortar from side elevation
CONDITION OF SAMPLE RECEIVED	The sample received consisted of a bag containing intact pieces of mortar plus fines. Size of largest piece = 68.41 mm x 42.14 mm x 35.47 mm Total mass of sample received = 185.4 grams

SUMMARY AND INTERPRETATION OF ANALYSIS RESULTS

The mortar appears to consist of a non-hydraulic to feebly hydraulic lime binder, most likely prepared as a 'hot mixed' lime mortar by slaking quicklime and sand together in one operation. To confirm the binder type and strength, further analysis by thin section (petrography) and X-Ray Diffraction would be required (in this sample the strength of binder is inferred from the hardness of the specimens examined). The colour of the mortar assessed against the Munsell Soil Colour Charts was found to be to 10YR 8/1 'white' to 10YR 8/2 'very pale brown'.

The mix ratio of the sample is approximately 1 part non-hydraulic to feebly hydraulic quicklime to 0.87 parts aggregate (by volume).

This mortar analysis report is NOT intended as a repair specification. Details of repair specifications based on information from this report should also take account of prevailing site conditions, including stone type and condition, location and function of the new mortar, building details, exposure, seasonal working etc.

ANALYTICAL PROCEDURES

The selected sample of material was dried to a constant weight and examined under a binocular microscope at x40 magnification. Degree of carbonation of the sample was determined using phenolphthalein indicator, which will react with any uncarbonated lime.

An assessment of the binder type was made by evaluating the physical characteristics of the mortar based on our knowledge, experience and understanding of materials.

Application of 10% Hydrochloric acid to the sample resulted in dissolution of the binder enabling relative proportions of lime (and gypsum) to aggregate to be determined; where appropriate, proportions of insoluble binder were determined and factored into this calculation. Subsequent aggregate characterisation was undertaken by means of dry sieve analysis and microscopic analysis.

The analysis results and interpretations made from it provide information on the composition and characteristics of the mortar sample(s) received by the SLCT laboratory. **Provided the sample was representative of the mortar generally**, the analysis will give a reasonable indication of the original materials and provide a **basis for specification** of repair mortars. If more detailed information is required (for example, for purposes of historic research) more sophisticated analytical procedures can be undertaken.

MORTAR EXAMINATION AND ANALYSIS

Plate 1. The total sample received (dish c.160mm diameter).

Plate 2. Showing a fresh face of the mortar. Scale is in mm.

PROCEDURE	OBSERVATIONS
PRELIMINARY VISUAL ANALYSIS OF SAMPLE	The sample was received as a fully carbonated intact piece of mortar plus fines. The sample is weak and requires little pressure to disrupt. There are frequent, irregularly shaped, hard lime inclusions throughout the sample. There was a small proportion small coal/burnt fuel fragments throughout the sample. The phenolphthalein indicator test confirmed that the mortar was fully carbonated whilst a water droplet test confirmed that the mortar was porous as the droplets were rapidly absorbed and the water diffused throughout the mortar.
EXAMINATION OF PREPARED SAMPLE BY BINOCULAR MICROSCOPE (X40 MAGNIFICATION)	The colour of the mortar assessed against the Munsell Soil Colour Charts was found to be 10YR 8/1 “white” to 8/2 ‘very pale brown’. The surface of the sample appeared porous and had a granular texture and the mortar appeared binder rich. Overall the aggregate appears relatively fine grained with buff/orange/grey coloured sub-angular to angular quartz grains dominating the mineralogy. The mortar showed voiding and evidence of calcite re-precipitation, along with vegetation growth and soiling, suggestion moisture movement through the mortar.

ACID DISSOLUTION & FILTRATION

PROCEDURE	OBSERVATIONS/COMMENTS	
DISSOLUTION OF BINDER USING 10% HCl	On addition of the acid to the powdered sample there was a moderate reaction producing a moderate amount of steam and foam. The reaction slowed after 5 mins but was still producing bubbles and the volume of steam was reduced. This shows a moderate to high free lime content.	
FILTRATION	GRADE: 20	PAPER TYPE: Whatman Type 41

CONSTITUENTS OF ANALYSIS SAMPLE

MATERIAL	WEIGHT (g)	COMMENTS
A: DRY WEIGHT OF ANALYSIS SAMPLE	36.04	Mass of sample analysed (before acid digestion).
B: DRY WEIGHT OF ALL INSOLUBLES	23.75	Insoluble residue recovered after acid digestion (before sieving).
C: DRY WEIGHT OF INSOLUBLE BINDER	0.00	Determined from microscopic examination of filter residue (presence of insoluble hydraulic components can be confirmed by XRD analysis).
D: (B-C) DRY WEIGHT OF AGGREGATE	23.75	Corrected for retention of hydraulic components or other non-soluble reaction products.
E: (A-D) DRY WEIGHT OF LIME	12.29	Including insoluble binder where present.
MOISTURE CONTENT (%)	7.89	Based on mass of sample before and after drying.
OTHER	-	Gypsum and other non-binder related contaminants or reaction products.

AGGREGATE GRADING & CHARACTERISATION

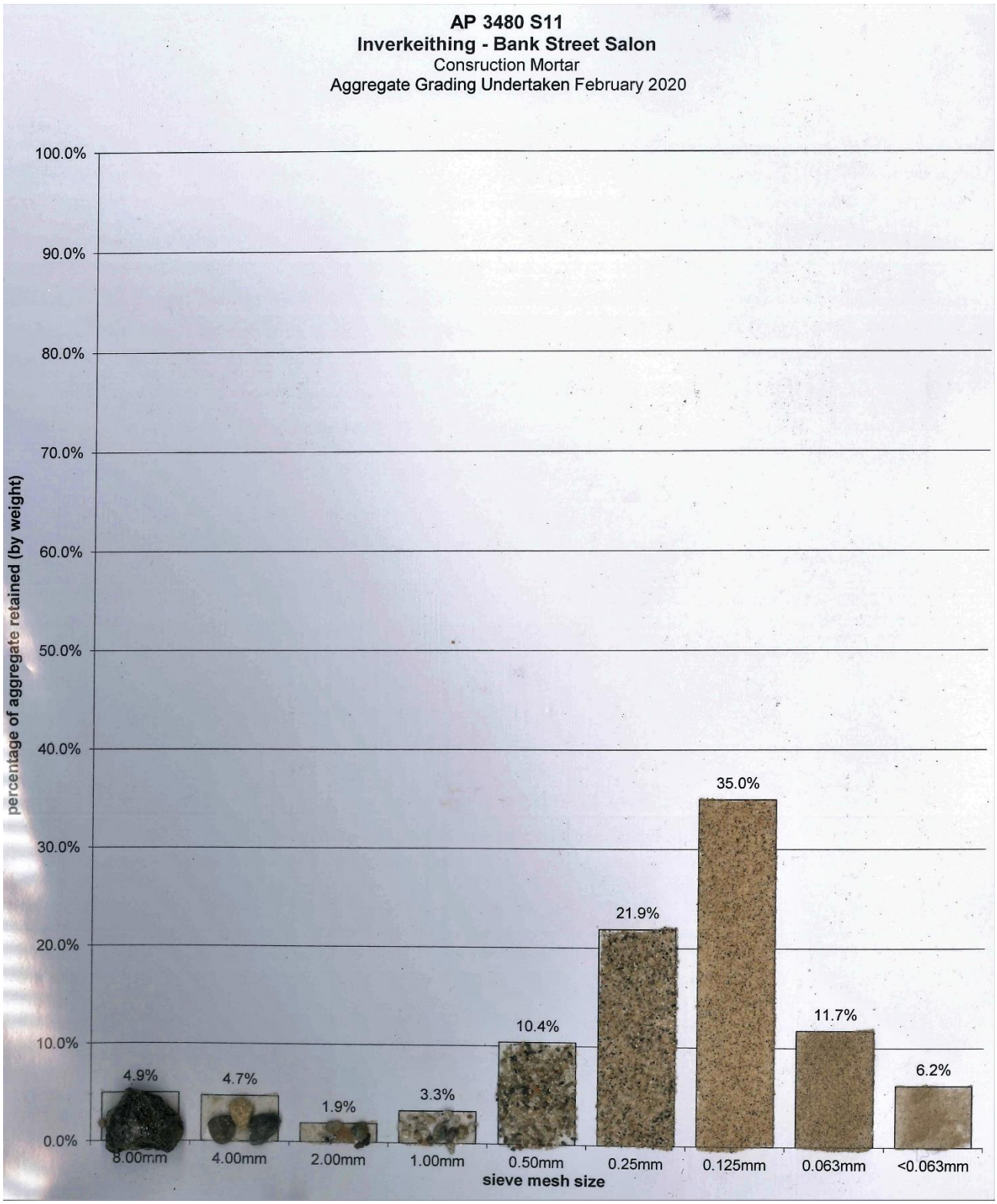
SIEVE PERFORATION SIZE*	AGGREGATE RETAINED (g)	UNDISSOLVED BINDER (%)	CORRECTED AGGREGATE WEIGHT (g)	% OF AGGREGATE	COMMENTS
8mm	1.10	0	1.10	4.9	Sub-angular to sub-angular well weathered lithic fragments
4mm	1.04	0	1.04	4.7	As above plus sub-rounded, sub-spherical quartz grains
2mm	0.43	0	0.43	1.9	As above
1mm	0.73	0	0.73	3.3	As above
500µm	2.31	0	2.31	10.4	As above
250µm	4.88	0	4.88	21.9	As above
125µm	7.79	0	7.79	35.0	Predominantly composed of angular – sub-angular quartz grains, cloudy, glassy, grey and orange/buff tinted and weathered lithic fragments
63µm	2.61	0	2.61	11.7	As above with indiscernible silt and clay.
< 63µm including filter residue	1.38	0	1.38	6.2	As above with indiscernible silt and clay.

***Sieve perforation sizes correspond to those stated in BS EN 1015.1:1999**

The aggregate isolated from this sample is moderately well graded and aggregate is retained from sieve size 8mm down with the highest percentage of grains being retained in sieve mesh 0.125mm with 35.0%. Well weathered lithic fragments and sub angular quartz make up the courser fractions. Smaller fractions are composed predominately of angular to sub-angular quartz grains and the buff/orange/cream tinted grains give the sand its overall pale brown colour. See aggregate profile below.

Because sand and gravel aggregates are ultimately derived from the weathering of solid rock, most aggregates contain course grained rock fragments and finer mineral grains. Physical weathering breaks down the rock fragments within the aggregate into the constituent minerals, resulting in smaller and rounder particles; chemical weathering breaks down unstable minerals, such as feldspars resulting in the formation of clay, which may be washed away. Both weathering processes eventually result in the formation of quartz-rich sand.

Aggregate Profile of the Aggregate Separated from the Mortar Sample



AGGREGATE MATCHING

The closest commercially available matching aggregate, from the SLCT Sands and Aggregates Database taking into account location, grading, grain size, colour and texture is Building Sand from Melville Gates Quarry (see aggregate profile below). This sand has been retained from sieve mesh size 4mm down, with the highest percentage of grains being retained from sieve mesh size 0.250mm with 41.5%. It is predominantly medium to fine grained with a uni-modal grain size distribution, lithic fragments give a slightly darker colour and a more buff colour is due to the silts and clays at finer fractions with quartz grains present throughout.

An alternative aggregate match is Building Sand from Lomond Quarry (see aggregate profile below). This sand has been retained from sieve mesh size 4mm down, with the highest percentage of grains being retained from sieve mesh size 0.125mm with 40.7%. It is well graded with a uni-modal grain size distribution, lithic fragments give a slightly darker colour and a more buff colour is due to the silts and clays at finer fractions with quartz grains present throughout. This sand has a slightly different grainsize distribution to the analysed sample but it is well graded.

Contact details for these quarries are listed below.

Angle Park Sand & Gravel Co. Ltd.,
Melville Gates Quarry,
Ladybank,
Cupar,
Fife
KY7 7RF

Tel.: 01337 830 303

Lomond Quarry,
Balsillie Farm,
Falkland Hills Road,
Leslie,
Fife
KY6 3HD

Tel.: 01592 741 590

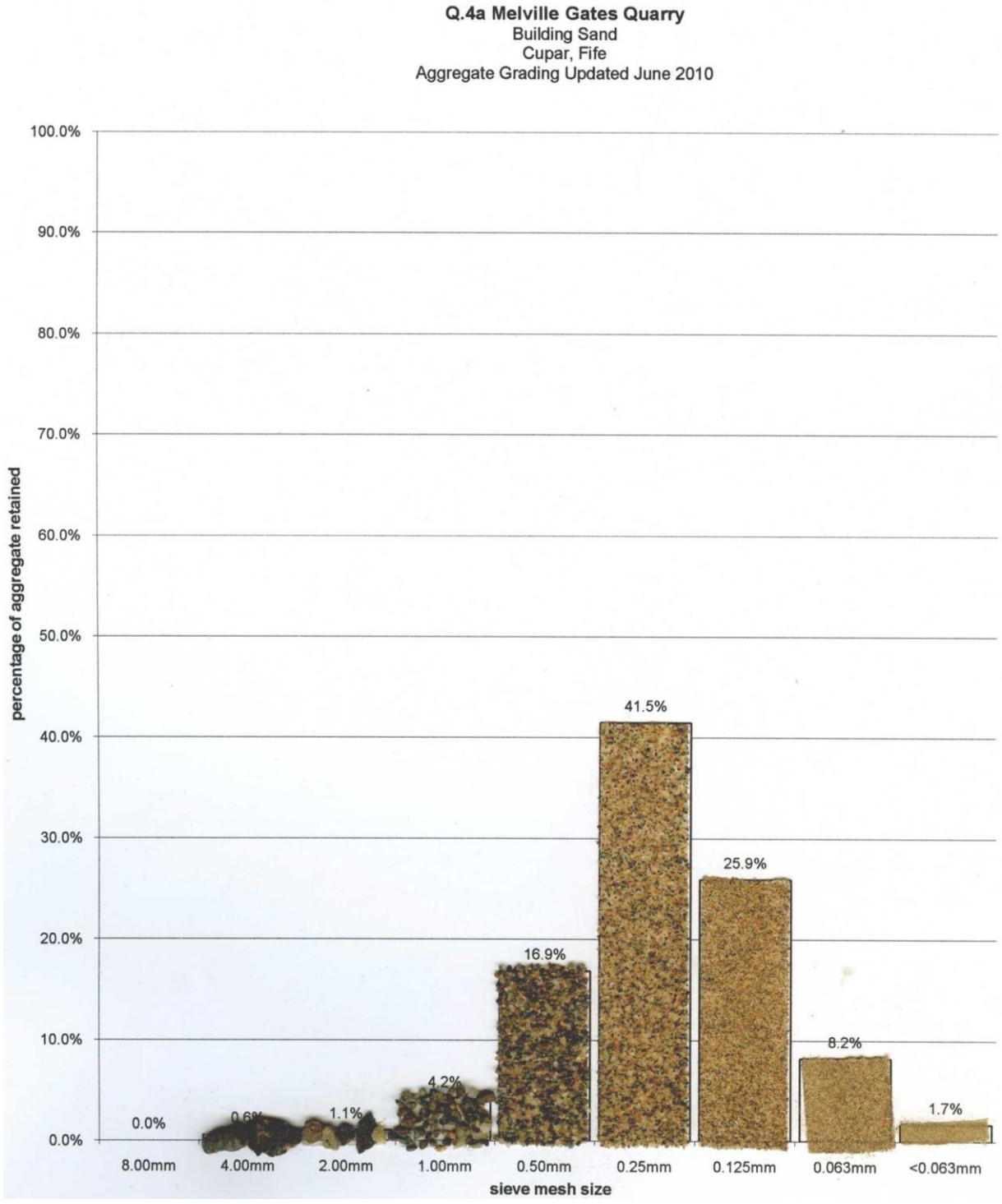
However, the named source(s) is/are not the only potentially suitable source(s) available, but is/are the closest, with respect to visual characteristics and physical properties, on the basis of the work carried out to date, on the sample submitted to examination.

The currently available aggregate samples held in the Scottish Lime Centre Trust's Aggregates Database are provided by the individual quarries/operators and therefore we have to assume that they are representative of the aggregate being produced at the time of receipt of the sample. As with all quarries the actual properties of the aggregate available will be dependent on the area being worked at any given time and it is, therefore, always prudent to obtain samples of the current production for comparison with the aggregate to be matched, prior to ordering supplies for a particular project/application.

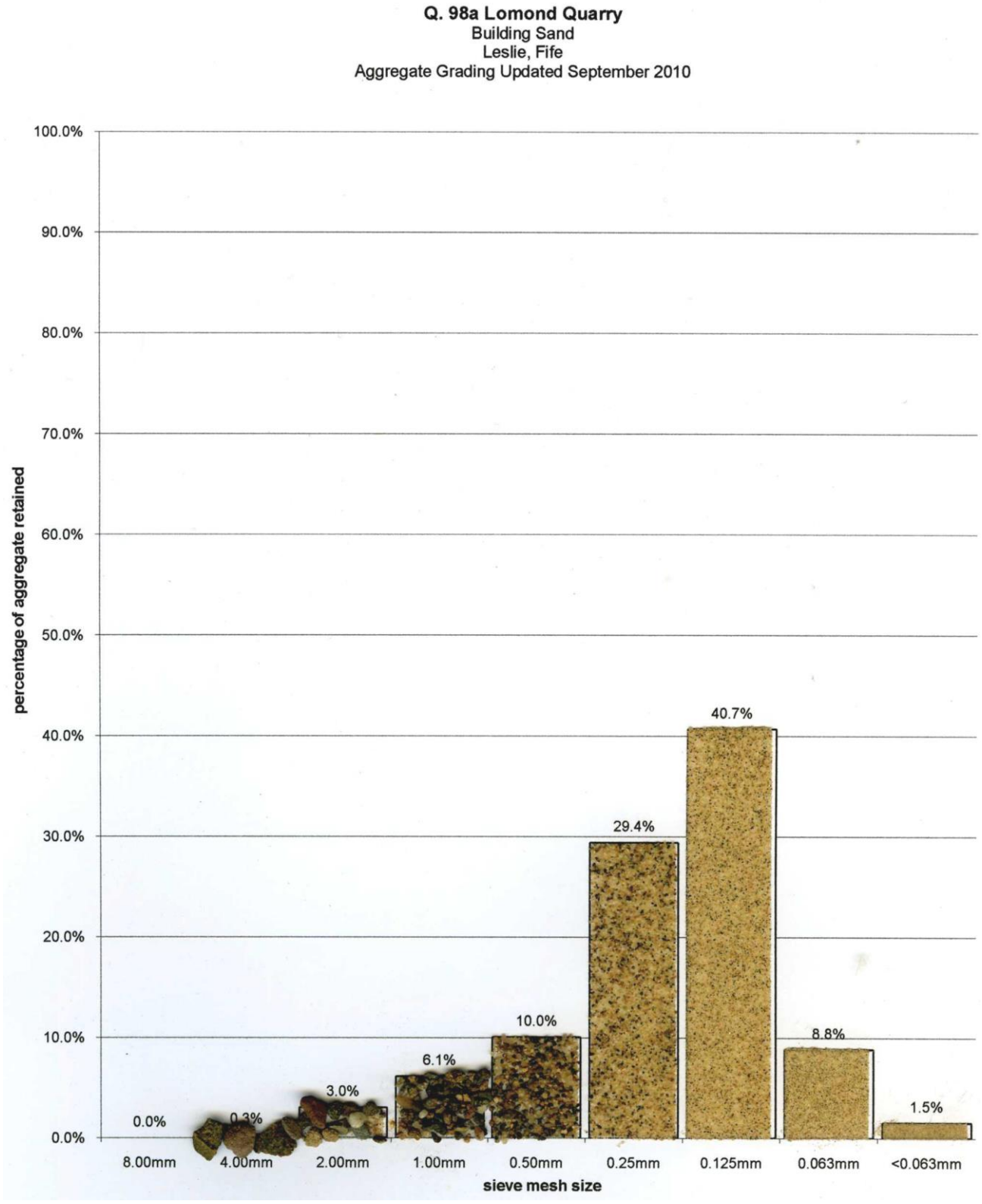
Quarries can change hands, open or close down with a relatively high frequency and therefore the source(s) identified above may become unavailable with no notice. If you are unable to obtain one of the above aggregates within 6 months of us completing this report then we will identify a new source free of charge (after this time period a charge will be incurred).

***If ordered please say that the aggregate was identified by the Scottish Lime Centre Trust.**

Aggregate Profile of the closest Matching Currently Available Aggregate: Building Sand, Melville Gates Quarry



Aggregate Profile of an Alternate Matching Currently Available Aggregate: Building Sand, Lomond Quarry



PROPORTIONS OF ANALYSIS SAMPLE

The sample proportions give the relative weights of aggregate and carbonated or set lime, unless otherwise stated.

LIME	:	AGGREGATE
1	:	1.9

PROBABLE ORIGINAL MIX

The original mix gives the relative weights of the mortar constituents as mixed on site and before carbonation. From the nature of the binding matrix of the mortar sample and from information gained from the analysis, it is probable that the mortar was made up from a non-hydraulic to feebly hydraulic quicklime.

1 PART NON-HYDRAULIC TO FEEBLY HYDRAULIC QUICKLIME	**:**	**3.1 PARTS AGGREGATE (BY WEIGHT)**

Please note that the proportions given above relate to the sample supplied, this is not a specification.

If a repair specification is required please contact us, and we can arrange for one of our surveyors/consultants to visit and inspect the building/structure, evaluate the relevant requirements, and subsequently provide recommendations and/or specifications for construction and repair work.

SCOTTISH LIME CENTRE TRUST

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MORTAR ANALYSIS REPORT

AP 3480
Port Street, Vennel Wall, Inverkeithing Stone and Slate Audit

Sample 17

Pointing/construction mortar

SITE	Port Street, Vennel Wall, Inverkeithing, Fife
CLIENT	Fife Historic Buildings Trust
DATE SAMPLE RECEIVED	10/08/2020
ANALYSIS DATES	10/08/2020 – 17/08/2020
ANALYSIS, INTERPRETATION & REPORT BY	Dr Katie Strang and Roz Artis
CLIENT REQUIREMENTS	Standard Mortar Analysis
STRUCTURE DATE	17th century (?); with 19th century alterations
STRUCTURE TYPE	Vennel wall
MORTAR DATING	original
LOCATION/ FUNCTION IN BUILDING	Pointing/Construction mortar from Vennel wall
CONDITION OF SAMPLE RECEIVED	The sample received consisted of a bag containing intact pieces of mortar plus fines. Size of largest piece = 75.47 mm x 127.49 mm x 91.25 mm Total mass of sample received = 131.15 grams

SUMMARY AND INTERPRETATION OF ANALYSIS RESULTS

The mortar appears to consist of a moderately to eminently hydraulic lime binder, most likely prepared as a 'hot mixed' lime mortar by slaking quicklime and sand together in one operation. To confirm the binder type and strength, further analysis by thin section (petrography) and X-Ray Diffraction would be required (in this sample the strength of binder is inferred from the hardness of the specimens examined). The colour of the mortar assessed against the Munsell Soil Colour Charts was found to be 10YR 8/2 'very pale brown'.

The mix ratio of the sample is approximately 1 part moderately to eminently hydraulic quicklime to 0.20 parts aggregate (by volume).

This mortar analysis report is NOT intended as a repair specification. Details of repair specifications based on information from this report should also take account of prevailing site conditions, including stone type and condition, location and function of the new mortar, building details, exposure, seasonal working etc.

ANALYTICAL PROCEDURES

The selected sample of material was dried to a constant weight and examined under a binocular microscope at x40 magnification. Degree of carbonation of the sample was determined using phenolphthalein indicator, which will react with any uncarbonated lime.

An assessment of the binder type was made by evaluating the physical characteristics of the mortar based on our knowledge, experience and understanding of materials.

Application of 10% Hydrochloric acid to the sample resulted in dissolution of the binder enabling relative proportions of lime (and gypsum) to aggregate to be determined; where appropriate, proportions of insoluble binder were determined and factored into this calculation. Subsequent aggregate characterisation was undertaken by means of dry sieve analysis and microscopic analysis.

The analysis results and interpretations made from it provide information on the composition and characteristics of the mortar sample(s) received by the SLCT laboratory. **Provided the sample was representative of the mortar generally**, the analysis will give a reasonable indication of the original materials and provide a **basis for specification** of repair mortars. If more detailed information is required (for example, for purposes of historic research) more sophisticated analytical procedures can be undertaken.

MORTAR EXAMINATION AND ANALYSIS

Plate 1. The total sample received (dish c.160mm diameter).

Plate 2. Showing a fresh face of the mortar. Scale is in mm.

PROCEDURE	OBSERVATIONS
PRELIMINARY VISUAL ANALYSIS OF SAMPLE	The sample was received as a fully carbonated intact piece of mortar plus fines. The sample is firm and requires significant pressure to disrupt, however once disrupted it is easy to powder. There are frequent, small (<2mm) irregularly shaped, cracked lime inclusions throughout the sample. Some inclusions were hard and appeared to contain relic cores (i.e the source limestone had not completely burnt through). There was a small proportion of burnt wood and coal fragments throughout the sample. The phenolphthalein indicator test confirmed that the mortar was fully carbonated whilst a water droplet test confirmed that the mortar was porous as the droplets were rapidly absorbed and the water diffused throughout the mortar.
EXAMINATION OF PREPARED SAMPLE BY BINOCULAR MICROSCOPE (X40 MAGNIFICATION)	The colour of the mortar assessed against the Munsell Soil Colour Charts was found to be 10YR 8/2 'very pale brown'. The surface of the sample appeared porous and had a granular texture and the mortar appeared binder rich. Overall the aggregate appears relatively fine grained with buff/orange/grey coloured sub-angular to angular quartz grains dominating the mineralogy. The mortar showed voiding and evidence of calcite re-precipitation – particularly towards the outer surface. The combination of this, along with vegetation growth and soiling, indicates significant moisture movement through the mortar.

ACID DISSOLUTION & FILTRATION

PROCEDURE	OBSERVATIONS/COMMENTS	
DISSOLUTION OF BINDER USING 10% HCl	On addition of the acid to the powdered sample there was a moderate reaction producing a moderate amount of steam and foam. The reaction slowed after 3 mins but was still producing some bubbles, however the volume of steam was reduced. This shows a moderate to high free lime content.	
FILTRATION	GRADE: 20	PAPER TYPE: Whatman Type 41

CONSTITUENTS OF ANALYSIS SAMPLE

MATERIAL	WEIGHT (g)	COMMENTS
A: DRY WEIGHT OF ANALYSIS SAMPLE	44.92	Mass of sample analysed (before acid digestion).
B: DRY WEIGHT OF ALL INSOLUBLES	16.30	Insoluble residue recovered after acid digestion (before sieving).
C: DRY WEIGHT OF INSOLUBLE BINDER	0.00	Determined from microscopic examination of filter residue (presence of insoluble hydraulic components can be confirmed by XRD analysis).
D: (B-C) DRY WEIGHT OF AGGREGATE	16.30	Corrected for retention of hydraulic components or other non-soluble reaction products.
E: (A-D) DRY WEIGHT OF LIME	28.62	Including insoluble binder where present.
MOISTURE CONTENT (%)	1.48	Based on mass of sample before and after drying.
OTHER	-	Gypsum and other non-binder related contaminants or reaction products.

AGGREGATE GRADING & CHARACTERISATION

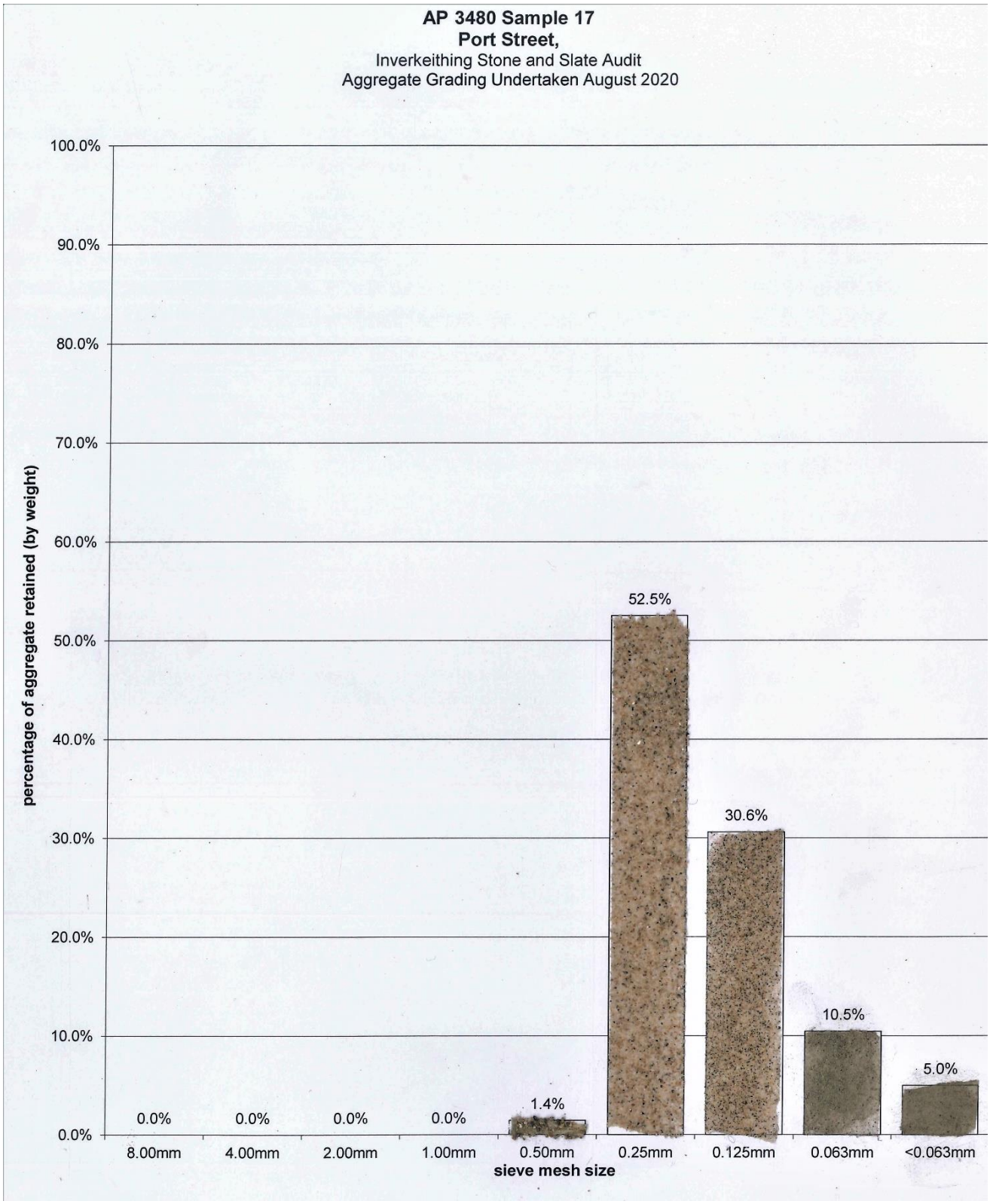
SIEVE PERFORATION SIZE*	AGGREGATE RETAINED (g)	UNDISSOLVED BINDER (%)	CORRECTED AGGREGATE WEIGHT (g)	% OF AGGREGATE	COMMENTS
8mm	0.00	0	0.00	0.0	
4mm	0.00	0	0.00	0.0	
2mm	0.00	0	0.00	0.0	
1mm	0.00	0	0.00	0.0	
500µm	0.23	0	0.23	1.4	Sub-angular to sub-angular well weathered lithic fragments and sub-rounded, sub-spherical quartz grains
250µm	8.44	0	8.44	52.3	Predominantly composed of angular – sub-angular quartz grains, cloudy, glassy, grey and orange/buff tinted and weathered lithic fragments
125µm	4.92	0	4.92	30.5	As above
63µm	1.68	0	1.68	10.4	As above with indiscernible silt and clay.
< 63µm including filter residue	0.88	0	0.88	5.4	As above with indiscernible silt and clay.

***Sieve perforation sizes correspond to those stated in BS EN 1015.1:1999**

The aggregate isolated from this sample is poorly graded and aggregate is retained from sieve size 0.500mm down with the highest percentage of grains being retained in sieve mesh 0.250mm with 52.3%. Well weathered lithic fragments and sub angular quartz make up the courser fractions. Smaller fractions are composed predominately of angular to sub-angular quartz grains and the buff/orange/cream tinted grains give the sand its overall pale brown colour. See aggregate profile below.

Because sand and gravel aggregates are ultimately derived from the weathering of solid rock, most aggregates contain course grained rock fragments and finer mineral grains. Physical weathering breaks down the rock fragments within the aggregate into the constituent minerals, resulting in smaller and rounder particles; chemical weathering breaks down unstable minerals, such as feldspars resulting in the formation of clay, which may be washed away. Both weathering processes eventually result in the formation of quartz-rich sand.

Aggregate Profile of the Aggregate Separated from the Mortar Sample



AGGREGATE MATCHING

The closest commercially available matching aggregate, from the SLCT Sands and Aggregates Database taking into account location, grading, grain size, colour and texture is Building Sand from Dalhousie Quarry (see aggregate profile below). This sand has been retained from sieve mesh size 1mm down, with the highest percentage of grains being retained from sieve mesh size 0.250mm with 55.2%. It is predominantly fine grained with a uni-modal grain size distribution, lithic fragments give a slightly darker colour and a more buff colour is due to the silts and clays at finer fractions with quartz grains present throughout. This sand is slightly coarser grained than the analysed sample, but it better in terms of grading/grain size distribution.

An alternative aggregate match is Washed Building Sand from Cowiehall Quarry (see aggregate profile below). This sand has been retained from sieve mesh size 0.55mm down, with the highest percentage of grains being retained from sieve mesh size 0.125mm with 57.8%. It is well graded with a uni-modal grain size distribution, lithic fragments give a slightly darker colour and a more buff colour is due to the silts and clays at finer fractions with quartz grains present throughout. This sand has a slightly different grainsize distribution to the analysed sample but it is well graded.

Contact details for these quarries are listed below.

Dalhousie Sand Quarry
Tillicoultry Quarries,
Bonnyrigg,
Midlothian
EH19 3JA

Tel.: 0131 654 9921

Cowiehall Quarry,
Patersons Quarries
Cowie
Stirling
FK7 7DH

Tel.: 01236 433 351

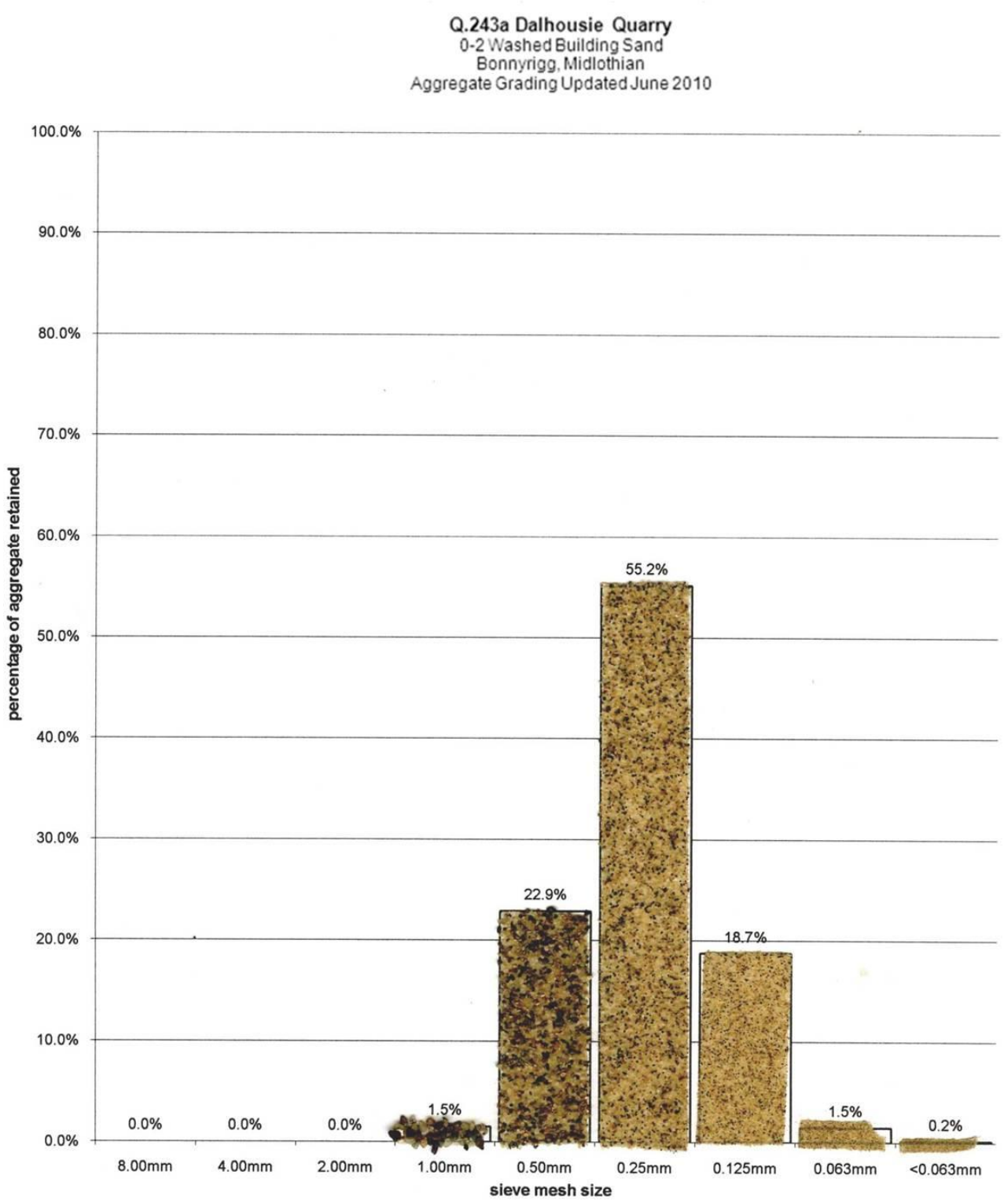
However, the named source(s) is/are not the only potentially suitable source(s) available, but is/are the closest, with respect to visual characteristics and physical properties, on the basis of the work carried out to date, on the sample submitted to examination.

The currently available aggregate samples held in the Scottish Lime Centre Trust's Aggregates Database are provided by the individual quarries/operators and therefore we have to assume that they are representative of the aggregate being produced at the time of receipt of the sample. As with all quarries the actual properties of the aggregate available will be dependent on the area being worked at any given time and it is, therefore, always prudent to obtain samples of the current production for comparison with the aggregate to be matched, prior to ordering supplies for a particular project/application.

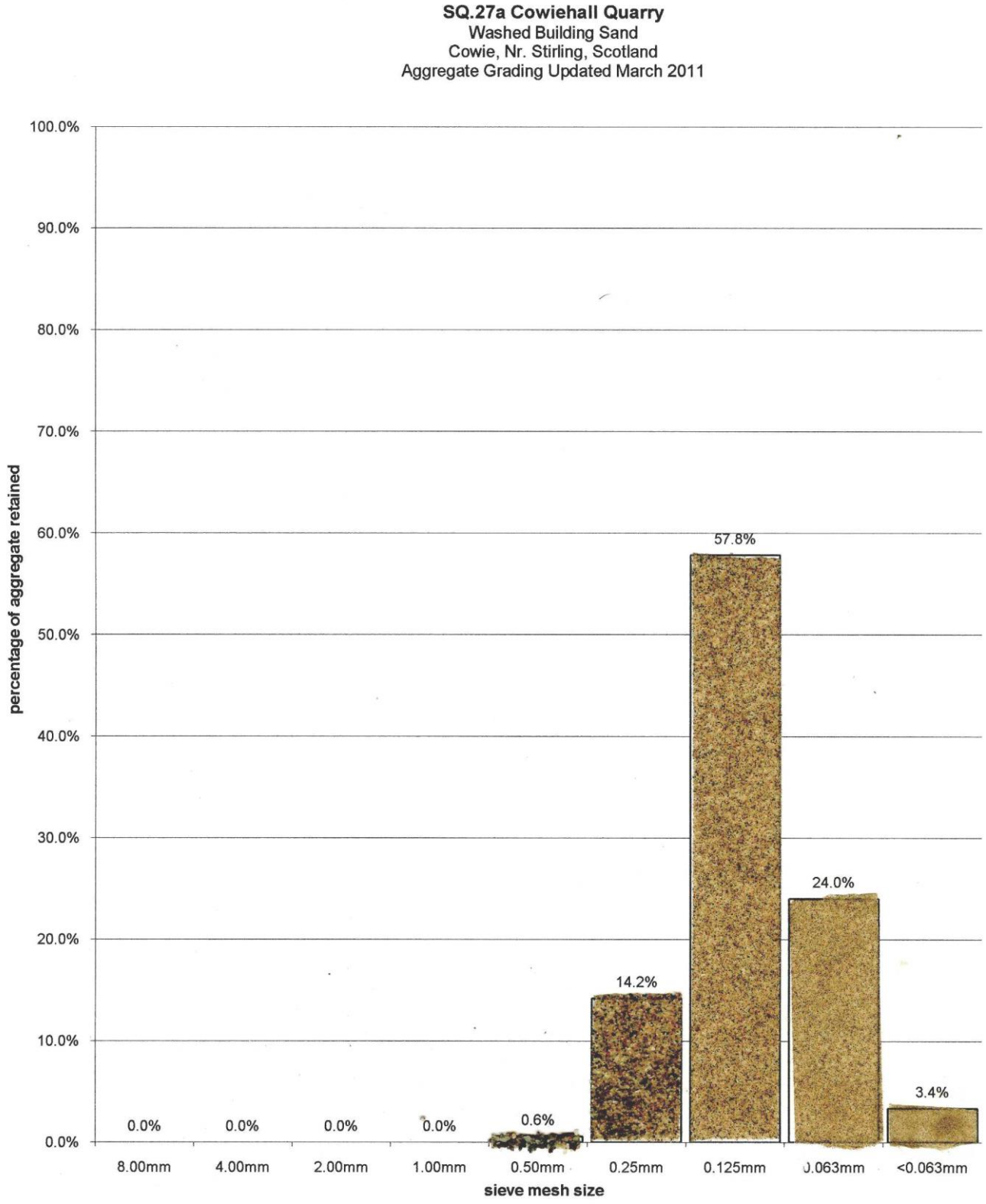
Quarries can change hands, open or close down with a relatively high frequency and therefore the source(s) identified above may become unavailable with no notice. If you are unable to obtain one of the above aggregates within 6 months of us completing this report then we will identify a new source free of charge (after this time period a charge will be incurred).

***If ordered please say that the aggregate was identified by the Scottish Lime Centre Trust.**

Aggregate Profile of the closest Matching Currently Available Aggregate: Washed Building Sand, Dalhousie Quarry



Aggregate Profile of an Alternate Matching Currently Available Aggregate: Washed Building Sand, Cowiehall Quarry



PROPORTIONS OF ANALYSIS SAMPLE

The sample proportions give the relative weights of aggregate and carbonated or set lime, unless otherwise stated.

LIME	:	AGGREGATE
1	:	0.6

PROBABLE ORIGINAL MIX

The original mix gives the relative weights of the mortar constituents as mixed on site and before carbonation. From the nature of the binding matrix of the mortar sample and from information gained from the analysis, it is probable that the mortar was made up from a moderately to eminently hydraulic quicklime.

1 PART MODERATELY TO EMINENTLY HYDRAULIC QUICKLIME	**:**	**0.7 PARTS AGGREGATE (BY WEIGHT)**

Please note that the proportions given above relate to the sample supplied, this is not a specification.

If a repair specification is required please contact us, and we can arrange for one of our surveyors/consultants to visit and inspect the building/structure, evaluate the relevant requirements, and subsequently provide recommendations and/or specifications for construction and repair work.